

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 59

STANDARD TEST SPECIMENS OF ZINC BRONZE

(Cu 88, Sn 10, Zn 2)—PARTS I AND II

PART I.—PREPARATION OF SPECIFICATIONS

BY

C. P. KARR, Associate Physicist

PART II.—MICROSTRUCTURE

BY

HENRY S. RAWDON, Assistant Physicist

Bureau of Standards

ISSUED MARCH 15, 1916



WASHINGTON
GOVERNMENT PRINTING OFFICE

1916

Monograph

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(Continued on p. 3 of cover)



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STANDARD TEST SPECIMENS OF ZINC BRONZE (CU 88, SN 10, ZN 2)—PARTS I AND II

Part I by C. P. Karr; Part II by Henry S. Rawdon

CONTENTS

PART I

	Page
I. Introduction and historical.....	5
II. Tests recommended and program adopted.....	8
III. Methods of preparing test pieces.....	9
IV. Methods of molding.....	11
1. Testing the molding sand.....	13
2. Gating and pouring of the molds.....	14
V. Methods of making the alloy.....	17
1. Stirring operation.....	19
2. Determination of pouring temperatures.....	20
VI. Preparation and mechanical tests of specimens.....	21
VII. Physical properties.....	22
1. General discussion of results of physical tests.....	22
(a) Comparison with the work of other investigators.....	27
2. Effect of manner of molding.....	29
3. Characteristics of typical samples.....	31
4. Elastic limit.....	33
5. Melting and critical ranges.....	33
VIII. Heat-treated specimens.....	35
IX. Choice of test specimens.....	38
X. Summary and conclusions.....	39
Appendix.....	42
Appendix A.—Suggested specifications for the preparation of standard zinc bronze (88Cu10Sn2Zn) test bars.....	42
Appendix B.—Comparison with Navy specifications.....	43
Appendix C.—Proposed standard specifications of the American Society for Testing Materials.....	44

PART II

	Page
I. Introduction	47
II. The equilibrium diagram	47
III. Structure of the cast alloy	50
IV. Relation between method of casting and microstructure	54
V. Appearance of specimens after tension test	55
VI. Correlation of microstructure and physical properties	56
1. Type of fracture	61
2. Coarseness of the dendrites	61
3. Eutectoid	62
4. Size and orientation of crystals	62
5. Oxide films and pits	63
6. Conclusion	64
VII. Microstructure as related to heat treatment	65
VIII. Etching of specimens	66
IX. Summary	67

Part I.—PREPARATION AND SPECIFICATIONS

I. INTRODUCTION AND HISTORICAL

The work of preparing an alloy of zinc, tin, and copper for the purpose of obtaining a standard form and dimension of test bar was undertaken by the Bureau of Standards at the request of a committee of the American Institute of Metals.

Preliminary accounts of this work have been published in the Proceedings of the American Institute of Metals for 1913 and 1914, which give a history of the inception of the work and an outline of some of the results obtained.

The zinc bronze—2 parts zinc, 10 parts tin, and 88 parts copper, also commonly known as Admiralty metal, Government bronze, and 88-10-2 alloy—has been studied experimentally by a number of physicists and metallurgists, but with the exception of the investigations of Webbert and of Skillman, all the work done has been concerned mainly with the effect of heat treatment at various temperatures from 250° to 800° C (482° to 1472° F). These previous investigations may be summarized briefly as follows:

I. M. Bregowsky and L. W. Spring¹ studied the effect of high temperatures on the physical properties of some alloys; among them were the so-called United States Navy bronze M, and United States Navy gun bronze G, which are of the same type as the above zinc bronze, but in addition contain small amounts of lead and iron.

Their physical properties, including tensile strength, elongation, and reduction of area, were determined at temperatures ranging from normal to 520° C (968° F). They found that the tensile strength of gun metal G reached its maximum value, about 37 000 pounds per square inch, at 300° F (149° C). Its elastic limit at normal temperature was 25 000 pounds per square inch, but dropped off steadily to about 8000 pounds per square inch at

¹ Proc. Internat. Assoc. for Testing Materials, Sixth Congress, New York, First Sec. VII.

950° F (510° C). Its elongation reached a maximum of 10 per cent at about 450° F (232° C), and the reduction of area at 300° F (148° C) of 8 per cent, while at 900° F (487° C) both elongation and reduction of area become zero.

In an article on "Metallography as an aid to the brass founder" H. S. Primrose² considered the influence of the pouring temperature on the strength of finished castings, the existence of blowholes in gun metal, and the examination of test pieces of this material under the microscope. Only two pouring temperatures are referred to, viz, 950° and 1100° C (1742° and 2012° F), but there may be some error or misprint about the first temperature stated, because a number of investigators have found the melting point of Admiralty gun metal to be about 995° C³ (1823° F).

He also shows for two casts of practically the same composition that the variation in the temperature of the castings and the consequent rate of cooling has a very distinct effect on the structure or crystalline formation of the metal. He finds that excessively rapid cooling renders gun metal very brittle.

H. S. and J. S. Primrose⁴ read a paper on the heat treatment of Admiralty gun metal—2 parts zinc, 10 parts tin, and 88 parts copper—wherein they considered the effect of heat treatment upon its physical properties at temperatures ranging from normal to 800° C (1472° F). Apparently but one pouring temperature (a little below 1100° C (2012° F)) was used in making the alloys. They conclude that no improvement may be expected by quenching, which lowers the strength of the material; annealing of the metal for 30 minutes increases very considerably its strength and elongation, the most satisfactory results being obtained after annealing 30 minutes at 700° C (1292° F). The homogeneity and other physical properties of the metal are correspondingly improved, but particularly the ability of the castings to withstand hydraulic pressure. These results after heat treatment are considered to be due to the removal of the eutectoid from the microstructure, which after annealing shows only the crystals of alpha solid solution.

² Journal of the Institute of Metals, May 24, 1910, Vol. IV, p. 248.

³ H. W. Gillett and A. B. Norton in Transactions of Amer. Inst. of Metals, 1913, Vol. VII, p. 341. (See also VII, 2 of present paper.)

⁴ Journal of Institute of Metals, Vol. IX, 1913, p. 158.

In a paper on bronzes John Dewrance⁵ considered the effect of adding small amounts of lead to gun metal. This material was submitted to heat treatment at 260° C (500° F), but no data were given as to the pouring temperature at which the alloys were made.

He showed that with 0.5 per cent of lead the breaking stress dropped from 16.5 tons per square inch to about 15.9 tons per square inch from normal temperature to 550° F (288° C), whereas gun metal without lead reached its maximum strength of nearly 17 tons per square inch at 300° F (148° C), dropped to 16.2 tons at 350° F (177° C), and fell rapidly to 9.5 tons at 400° F (214° C), and at all higher temperatures up to 700° F (371° C) was inferior to zinc bronze containing 0.5 per cent lead.

In the elongation tests the leaded zinc bronze reaches its maximum elongation of 18 per cent at 550° F (288° C) and above 360° F (182° C) its elongation is superior to that of the bar containing no lead.

Some additional experiments by H. S. Primrose⁶ confirmed the fact that only an almost inappreciable change in structure was produced by any annealing conducted at a temperature much below 700° C (1292° F), even with 0.5 to 1 per cent of lead present.

Messrs. Longbottom and A. Campion⁷ studied the behavior of Admiralty gun metal at high temperature. They found that the maximum stress, about 13 tons, remains practically constant to 200° C (392° F), then falls off, reaching almost zero at about 750° C (1,382° F). The elongation rises to a maximum at about 150° C (302° F), then falls rapidly, reaching a constant low value between 350° to 550° C (662° to 1,022° F). The reduction of area follows almost exactly the same course, while the modulus of elasticity is constant up to about 200° C (392° F), and then falls rapidly.

L. P. Webbert⁸ discussed the strength of nonferrous castings, referring particularly to the method of longitudinal gating of gun-metal castings, and also considered the direct attachment of the test bar to the casting as a means of interpreting the properties of the casting. Temperatures were taken at the furnace.

⁵ Journal of Institute of Metals, Vol. XI, 1914, pp. 214, 228.

⁶ Journal of Institute of Metals, Vol. XII, 1914, pp. 254, 256.

⁷ Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1914, Newcastle meeting; Journal of Institute of Metals, 1914, Vol. XII, p. 281.

⁸ Proceedings Amer. Soc. for Testing Materials, Vol. XIV, 1914, p. 145.

The object of these investigations was to note the changes in strength that occur in different thicknesses of metal castings made from nonferrous metals met with in engineering practice, what strength to expect from different alloys, and a study was made of different types of test specimens. These tests were carried out with the test bar attached to the casting by means of a thin gate running from the casting along the longitudinal axis of the test bar.

V. Skillman⁹ considered the question of the test specimen of a nonferrous alloy in which he referred to the different sand-cast shapes and also to a bar cast in an open chill mold, and pointed out the desirability of more exact definition of test bars.

In all of the above investigations some particular phase of the problem has been studied, but in none of them have all of the variables which influence the ultimate determination of the principal physical properties been taken into consideration, and with the exception of Webbert's investigations a sufficient number of test bars do not appear to have been examined to give conclusive results except in minor particulars.

Some of the work of these investigators is referred to elsewhere in the text.

II. TESTS RECOMMENDED AND PROGRAM ADOPTED

The committee of the American Institute of Metals in consultation with this Bureau considered it would be desirable to determine the following properties of this alloy:

1. Tensile test with determination of tensile strength, elongation, and reduction of area, including the recording of the stress strain curve.
2. Compression test.
3. Determination of (a) heat conductivity, (b) electrical conductivity, (c) coefficient of thermal expansion, (d) hardness, (e) specific gravity.
4. Shrinkage.
5. Mechanical properties up to 800° C.
6. Hydraulic test.

⁹ Transactions Amer. Inst. of Metals, Vol. VII, 1913, p. 360.

7. Resistance to corrosion by (a) ammonia, (b) sea water, (c) fresh water, (d) Turtle Creek water.
8. Resistance to erosion by (a) steam, (b) sand blast.
9. Shear test.
10. Impact test.
11. Fatigue test.
12. Thermal analysis.
13. Study of microstructure.

For the present investigation the following tests were finally decided upon to be carried out in connection with the methods of preparing the alloy:

1. Experiments to determine the best form of test block and test piece. A sufficient quantity of the alloy is to be melted so as to cast from the same crucible all of the various blocks proposed in a paper by Jesse L. Jones¹⁰, and also a cast-to-size test bar both in green and in dry sand.

2. Tests to determine the best casting temperature, to be made after the best form of test block and test piece have been determined.

3. Tests of the following sorts on all the bars cast for the tests Nos. 1 and 2 above: (1) Tensile test, including the determination of elongation, reduction of area, and tensile strength, and recording of the stress-strain curve; (2) compression test; (3) study of microstructure; (4) thermal analysis.

With the exception of the compression tests, this program has been carried out as planned.

III. METHODS OF PREPARING TEST PIECES

The operations of casting and molding, etc., as well as the experiments on the variations in foundry practice, are described in considerable detail so that the exact bearing of the results obtained may be the more readily appreciated, and for the reason, well known to practical foundrymen, that minute variations in seemingly insignificant details are often crucial in determining the resulting properties of the cast metal.

In all, 10 series of test blocks were cast. (See Table 1 and Figs. 1 and 3.) The first series consisted of various sizes of test blocks,

¹⁰ Transactions Amer. Inst. of Metals, Vol. VI, 1912, p. 173.

grouped about a central gate and poured flat in green sand. The second series was poured flat in dried sand; the first half of this series consisted of the same patterns arranged in practically the same way as the first series, as shown on the first diagram of Fig. 1. The latter half of the second series was so arranged that the patterns were of only two different kinds, viz, the cast-to-size shape and the 1-inch diameter cylindrical shape which balanced each other and corresponded more closely to each other in mass. (See Fig. 3.)

The third series was poured vertically in dry sand as indicated on the second diagram of Fig. 1.

The barrel and cylindrical shapes of the fourth series were poured vertically in dry sand with the bulb reservoir at the entrance to each mold, as shown in the diagram *c* of Fig. 1. As the cast-to-size shape did not prove successful by this method, the pouring head was transferred to the end of the runner and the mold was supplied with metal from one side of the runner, all other conditions remaining the same.

The fifth series was poured flat in green sand, as indicated by the diagram *d* of Fig. 1.

The sixth series was poured flat in dry sand, as indicated by the same diagram of Fig. 1.

The seventh series was poured vertically in dry sand, with bulb attachment to test block, and with the pouring head at one end of the runner.

In series VIII all specimens were reserved for heat-treatment tests. Part of these were poured flat in dry sand and the other part poured vertically in dry sand.

The ninth series was distinguished from all others by the fact that the metal used consisted entirely of turnings accumulated in machining the test bars cast in all of the previous series. Part of this series was poured in an iron chill mold, and part as indicated in Fig. 1, *d*.

The tenth series was poured in two ways, one-half poured flat in dry sand and the other half poured vertically in dry sand. Bulb attachments were provided at the entrance of each mold, and the pouring head was arranged opposite one end of the runner. It was also distinguished from the other series by reason of the metal

used, which consisted of gates, runners, sprue heads, and floor spillings from previous casts; in other words, all the metal had been used before and in foundry parlance was what is known as "re-melted metal."

TABLE 1
Schedule of Castings

[Shapes: A=cast-to-size, B=cylindrical, C=barrel, D=chill.]

Series	Shapes used	How poured	Patterns in each flask	Shapes	Metal feed	Range of temperatures covered
						°C
I	4	Flat; green sand.....	5	A, B, C, D	Plain runner..	1050-1230
II	4	Flat; dry sand.....	a 5	A, B, C, D	do.....	1060-1240
			b 6			
III	2	Vertical; dry sand.....	6	A, B	do.....	1050-1230
IV	4	do.....	3	A, B, C, D	Bulb gate.....	1075-1395
V	4	Flat; green sand.....	3	A, B, C, D	do.....	1190-1325
VI	4	Flat; dry sand.....	3	A, B, C, D	do.....	1120-1365
VII	4	Vertical; green sand.....	3	A, B, C, D	do.....	1180-1225
VIII	3	Flat and vertical; dry and green sand.	3	A, B, C	do.....	1120-1345
IX	2	Flat and vertical; dry sand and chill..	3	A, D	do.....	1055-1270
X	2	Flat and vertical; dry sand.....	3	A, D	do.....	1255-1270

^a First half.

^b Second half.

IV. METHODS OF MOLDING

The molding sand used for the body of the mold was No. 2 Albany, mixed with pit Ottawa sand, which is almost pure silica. The facing sand was composed of oo Crescent sand, two parts to one part bench sand.

The molding was started by mixing two parts of old molding sand to one part of new Albany sand. To 11 pounds of this mixed sand, 1½ pounds of pit Ottawa sand were added and the whole thoroughly mixed together. This mixture worked admirably and this treatment produced an open-bodied sand well adapted to green-sand molding operations.

For dry-sand molding the method pursued was somewhat different. The body of the mold was composed of old, new, and Ottawa sand of about the same proportions and thoroughly mixed. In putting up the molds the body sand need not be so dry as for green-sand molding. When the mold was made it was sprayed

with a solution of molasses and water to such a consistency that the liquid left a decidedly sticky sensation to the fingers. To obtain this condition make a mixture of two parts of sirup to three parts of water by volume. Each mold was then placed on the shelf of a drying oven and as a rule dried for 20 minutes; if an inspection of the dried mold showed any indication of moisture, evidenced by the darker color of the sand, the mold was again dried until this discoloration disappeared. The hot molds were

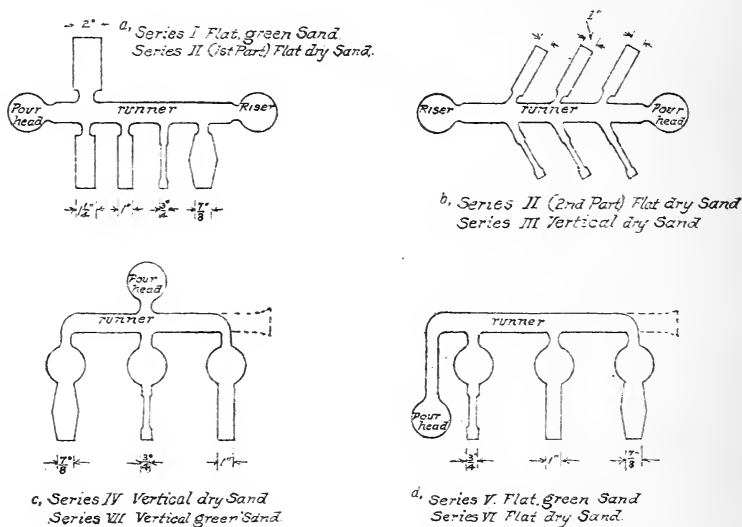


FIG. 1.—Methods of pouring bronzes. Series I-VII, inclusive.

allowed to become perfectly cold on the pouring bench before they were closed up and poured. The ramming of the flask when test bars are to be molded is an important part of the operation. The body sand was shoveled into the flask in the usual manner, filling it up to about $1\frac{1}{2}$ inches above the rim of the flask, then it was crowded down into place by hand and packed by a kneading pressure of the fingers, starting at one edge and working all around the edge of the flask to the point of beginning and then gently kneaded down through the center portion. Then the whole sur-

face was rammed lightly with the wedge-shaped end of the rammer, followed by a uniform, light ramming with the rounded end of the rammer. The whole surface was then sprinkled over with loose sand from the tub and stricken off smooth with an iron bar; sand was then slightly spread over the surface in the usual manner, smoothed and crowded down with the moldboard. The smoothed surface was tested at different places by finger pressure to determine whether the ramming had been uniform, especially if the flask was to be poured flat, or if poured vertical the lower part of the flask was rammed harder than the upper surface so that the casting would not be swelled when poured.

If the flask was to be poured flat, the pouring hole was molded about the wooden plug, and the sand about the plug was rammed much harder than the rest of the mold, so as to resist any possible cutting action of the pouring stream of metal that might impinge upon the sides.

In dry-sand molds the runners and the pouring head were dusted with powdered graphite and slicked smooth by a light pressure of the fingers before the surface was sprayed with molasses water. In order to insure that the molds contained no loosely adhering particles of sand which might be dislodged by the pouring stream, it was found desirable to carefully inspect the runners and pouring heads throughout their entire area and length, and where any roughness showed, due to cutting of gates or passages, to smooth such surfaces down by a pressure of the thumb or fingers, and also to avoid all sharp or angular turns in the metal channels.

1. TESTING THE MOLDING SAND

According to the best foundry practice, the quality of a molding sand is considered to depend upon its cohesiveness, its refractoriness, texture, porosity, permeability, and durability. These factors have been clearly defined in a brochure on Foundry Sands, prepared by Heinrich Ries and J. A. Rosen.¹¹ The texture of the sand is determined by observing the percentage of the sample which is retained on sieves of different mesh. This test is the one

¹¹ Published by the Board of Geological Survey of Michigan, May 6, 1908.

most commonly referred to as the foundry test for molding sand. Messrs. Ries and Rosen advocate the following method:

Fifty grams of the sand are put into an 8-ounce bottle and the latter half filled with water. The mixture is then placed in a mechanical shaker for half an hour in order to disintegrate it, after which it is washed through a set of 20, 40, 60, 80, and 100 mesh sieves. The sand on each is dried and weighed. The amount passed through the 100-mesh sieve is received in a glass jar. When all of the water and suspended matter has run through the sieves, the contents of the jar are stirred up and allowed to stand 45 seconds. The amount that settles during this interval of time consists almost entirely of fine sand and grains of silt, ranging from $\frac{1}{150}$ to $\frac{1}{250}$ inch in size and is classified as $\frac{1}{250}$. The water with the suspended clay is then decanted off. Since some clay is drawn down with the silty particles, the washing process is repeated in order to remove the remaining clay. The water over the silt and fine sand is removed in part by decantation and the residue evaporated to dryness as is also the solution containing the suspended clay. If the sample be a bank-molding sand, it should first be passed through a 10-mesh sieve to remove twigs, other organic matter, and gravel.

The percentage of material retained on each sieve is found by dividing the weight of sand on each sieve by the total weight of the sand and multiplying by 100. The majority of molding sands have a specific gravity of 2.6.

The object of the sieve test, as above, is to determine the texture of a molding sand. This property is of primary importance. It may affect the cohesiveness of the sand; it stands in close relation to the permeability of the sand, and to a large degree determines the grade of metal that can be cast into it.

2. GATING AND POURING OF THE MOLDS

Fig. 1 shows the method of gating pursued for the first seven series. (See p. 12.)

The eighth series was poured vertically in dry sand, somewhat like the sixth series, with this exception, that although the runner location was the same the flask was tilted up on end. The pouring head was placed opposite the end of the runner so that the molded

depressions would be filled up from the side as the molten metal rose up from the bottom of the runner. The circular opening marked "pouring head" on the figure was closed up and formed a pocket at the bottom of the runner, which caught and retained nearly all of the oxides, dross, and dirt which had risen to the top surface of the pot, but which in pouring was cast into and filled the pocket first. This device afforded the molded depressions a chance to fill up with clean metal.

The ninth series was poured in a chill bar and from turnings run down directly in the pot.

The tenth series was poured flat in dry sand in the same manner as the sixth series.

In the first series and first half of the second series the gating was found to be defective, inasmuch as the molds to be filled from the center runner were of different dimensions, and, since they drew from the same supply, unequal shrinkages were produced; hence, uniform results could not be secured. In addition to this, the heavier sections showed results inferior to the thinner sections because in machining each specimen down to a uniform standard section the skin formed at the quickly cooled surfaces of the larger specimens was cut away, leaving only the softer core to withstand the stresses, which in the case of the thinner specimens were imposed upon the more quickly chilled harder shafts. This slower cooling of the heavier pieces permitted of a different crystal formation and a different phase formation in the solid solution of the metal than would be possible in the thinner and more rapidly cooled sections, and consequently in the latter case produced much higher tensile strength. To obviate these defects the patterns were changed in the last half of the second series so that they were more equal in volume, more uniform, and better results as to tensile strength and ductility were immediately secured.

In the last part of the fourth series the gating was changed, as represented by the dotted lines, which represent the new position of the pouring head, the old pouring head being stopped off.

In the seventh and all subsequent series poured vertically, the diagram shown for the fifth series, with the dotted lines, indicates

the position of the pouring head, the old pouring head having been closed up and used as a sump to catch slag and scoriæ.

The process of pouring the chill bars furnished some data of importance. To make this clear it is necessary to explain that the chill bars were poured as flat as possible, almost level, in fact; the filling of the mold began at one end and then the metal flowed on to the farther end. In the pouring, the scum and dross which were carried down by the pouring stream accumulated in the front end of the mold; this scum, which chilled faster than the molten metal, was more sluggish in its flow, and was also held back more or less by the frictional resistance of the sides of the mold. When machined down it was found that as a rule the specimen at this end of the mold was softer than at the far end which contained the finer metal, and that sometimes the penetration of the dross into the mold had reached into the core of the specimen itself. Now, the practice had been established, for the purpose of identification of the specimen and its pouring position, of numbering the pouring end first. It was found as a rule that the far or purer end of the mold yielded the more perfect specimen, the one that gave the highest tensile result and the greatest elongation. To illustrate this point attention may be called to the results on a chill bar, cast in the fourth series, at a temperature of 1150° C (2102° F). This block is always long enough to make three finished test bars. Their numbers were, respectively, 478, 479, and 480. Their tensile strengths were 37 800, 42 200, and 45 400 pounds per square inch, and their elongations 4 per cent, 8.5 per cent, and 11 per cent, respectively. Now 4.5 per cent is considered a good elongation for a chill bar. It may be seen from these results how important it is that the pouring stream should be free from dross and scum of all kinds, and this result may be promoted by the use of a pouring lip, or of a cover over the metal which will hold the dross back. It also shows another interesting fact—that with pure metal, the higher the tensile strength of a specimen the greater is the elongation that may be expected. The standard of performance in such a case may undoubtedly be raised by the use of the greatest of care to insure the purifying of the alloy.

In the third series (Fig. 1, *b*) the patterns were better balanced and arranged on opposite sides of the runner, and although internal

stresses still developed through inadequate feeding supply fairly good results were secured.

In the fourth series (Fig. 1, *c*) a bulb reservoir was for the first time molded with the test piece opposite each mold, which supplied an adequate amount of metal to take up the shrinkage. By this device internal stresses developed by cooling were almost wholly avoided. In this series the center mold proved defective because it was directly opposite the pouring gate. This arrangement permitted the center mold to catch all the dross, oxides, and scorïæ naturally carried down by the entering column of molten metal. To avoid this the pouring head was shifted to one end of the runner without changing the position of the patterns in the molding operations, whereupon better results were immediately obtained. This bulb, as indicated on Fig. 1, was about $2\frac{1}{4}$ inches in diameter.

The fifth, sixth, and tenth series were gated as shown in Fig. 1, *d*. The seventh was gated in the same manner as the revised fourth series; that is, the pouring head was placed opposite one end of the runner, and the circular molded portion acted as a pocket or sump to collect the dross and scorïæ so that the molds could be cleanly fed with metal. Unless sufficient space is provided in the runner and in the pouring head for the metal to enter the mold in a solid steady stream, and at the same time to allow sufficient space adjacent to the descending column of metal, the gases developed will have no opportunity to escape and free themselves from the metal. The consequences will sometimes be a choked mold, which does not fill up uniformly, or castings that have become permeated with gas holes, and therefore porous, or both undesirable results may accrue. To secure good results, it therefore becomes necessary to have the runner molded with the patterns so as to secure a smooth and uniform passage for the flow of metal, a channel which can not be obtained by cutting out after the mold is made.

V. METHODS OF MAKING THE ALLOY

The furnace used was a cylindrical, brick-lined chamber with separate removable iron grate bars, and provided with a conical-shaped cast-iron cover. It was of the pit type, coke fired, with

natural draft, and was provided with a chimney about 60 feet in height. It was found necessary to break the coke to a uniform size, as the space between the pot (a No. 40) and the furnace lining was only about $2\frac{1}{2}$ inches in width. In the bottom of the furnace, resting on the grate bars, an old pot was cut down to about two-thirds of its former height and was inverted to form a permanent support for the melting pot, so that the latter would not settle down on the grate bars as the coke burned out, and also for the purpose of keeping the melting zone at a fixed height, viz, about 4 inches above the bottom of the pot. The average time of melting the charge of about 65 pounds was about two and one-fourth hours. The fuel used was 72-hour coke, kept dry. One heat per day was poured.

The pot was charged as follows: In the bottom an inch layer of charcoal broken into pieces about the size of a hickory nut was placed evenly. The copper ingots of the weighed charge were set on this bed of charcoal, small pieces of gates, sprue heads, or defective castings were then put in to fill the crevices between the ingots of copper and to level off the surface up to the top of the pot. Broken charcoal, very small pieces with no dust, were added as a protective covering, and the graphite cover was placed over the entire charge. The coke fire was then urged to its utmost. As fast as the body of coke burnt down what remained was crowded down firmly with a heavy iron bar, fresh coke added up to the top of the pot and sometimes strewn over the cover itself, and the firing then proceeded until the charge was melted. The graphite cover was then removed and the molten metal stirred. When the copper was completely melted, the tin was added and carefully stirred in. When the metal had come to a somewhat higher temperature, the zinc, after being previously heated, was added and stirred into the molten bath as rapidly as possible. All of the charge now being in the pot and ascertained to be in a molten state, the fire was accelerated and the charge heated up considerably higher; in fact, until lambent zinc flames began to be seen around the edges of the metal surface adjoining the pot.

1. STIRRING OPERATION

The object of stirring the molten metal thoroughly was to promote the intimate mixture of the components of the alloy. If the stirring rod be worked up and down and from side to side, as well as moving about in a circular path, the various particles of the alloy will be brought into more intimate contact than if only one kind of motion be followed in the stirring. The rotary motion is the one generally used, but if also accompanied by a vertical pumping movement of the stirring rod, the heavier particles at the bottom will be displaced, the lighter particles dragged downward, and a thorough diffusion of all the particles and greater uniformity of mixture will be obtained.

A graphite rod is inserted into an iron sleeve about 12 inches long, into which has been cut a $\frac{1}{10}$ -inch slot. This sleeve is set in an iron collar $1\frac{29}{32}$ inches inside dimension by $\frac{5}{8}$ inch long, which is secured to the sleeve and tightens the clutch on the graphite rod by means of a $\frac{1}{4}$ -inch standard set screw. At one end of the sleeve the rod is inserted and the other end is screwed into a $\frac{3}{4}$ -inch iron pipe, which is made of any length desired. (Fig. 2.)

There is the objection to both the iron and graphite rod that they absorb heat from the molten metal and reduce its temperature if the rods be introduced in a cold state; they must be heated to a cherry red heat before being plunged into the metal. The disadvantage of the iron rod is that if it be kept in the metal long enough to stir the mass effectively little globules of the iron drop from the iron poker into the metal alloying with and contaminating the melt.

The advantages of the graphite over the iron rod for stirring purposes may be readily seen by considering the fact that the consumption of the graphite rod in contact with the molten metal produces a gas and does not furnish any element capable of combining with the constituents of the alloy unless it be the silicon which may be present in only such a slight amount that no deleterious effects are perceptible in the cast alloy; this result is confirmed by the fact that chemical analysis fails to show any silicon in the alloy. The rod burns away gradually, the combus-

tion of the rod taking place chiefly at the bottom until the $1\frac{1}{2}$ inches diameter of the section burns away to a point. The rod may be used safely, as a rule, for not less than 30 consecutive heats, and this average may sometimes be increased to 40 heats.

A very satisfactory rod is one made of Acheson graphite, which is almost pure carbon. It is a soft, dense, brittle substance, and in its use as a stirring rod must be handled with some care. A rod of so large diameter as specified seems capable of offering the transverse resistance to fracture required by the stirring operation. Its fragility comes into question if it be carelessly dropped from the workman's hand when the rod has served its purpose. A good method of preserving it from transverse fracture is to

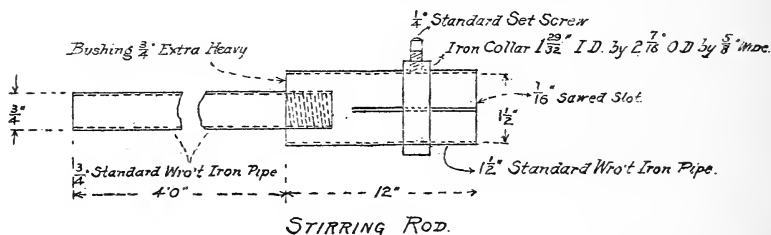


FIG. 2

plunge it vertically into a barrel of loosely packed sand immediately after being withdrawn from the furnace.

2. DETERMINATION OF POURING TEMPERATURES

The temperature was taken while the metal was still in the furnace by means of a Hölborn-Kurlbaum type of the Morse optical pyrometer, or after the pot was removed from the fire, by means of a thermocouple consisting of platinum, platinum-iridium (10 per cent). The platinum couple was incased in an inner tube of quartz open at both ends for the insulation of the two wires from one another, and the whole sheathed in a quartz tube closed at one end. The closed end of the quartz tube was held over the molten metal until the temperature of approximately 600°C (1112°F) was indicated, and then plunged to within about 6 inches of the bottom of the pot. The needle of the registering millivoltmeter rose steadily and rapidly to a constant position when the reading was taken, and there was no perceptible lag

noticed after the couple had been plunged into the metal. It was found that all slag or scoriae adhering to the tube from the contents of the pot could, when cold, be removed easily by one's fingers without detriment to the tube. A set of tubes was used for months without any marked deterioration.

The thermometer used for taking the temperature of the cold junction was wound about with one of the copper leads from the Pt wire of the thermocouple at one end and the other end wound about in the same manner with copper lead of the Pt-Ir wire. The thermometer was fastened to a thin board with insulated wires and the whole secured to the upper end of the outer quartz tube so as to become rigidly a part of the device. This method prevented any undue pulling strain on the tubes or the connections, and this arrangement became a practicable foundry device, with which the pouring temperature of one or more pots could be taken successively. It was found that after a month's training and experience almost any intelligent workman could take the pouring temperatures accurately and rapidly. This experiment was undertaken to show that although operating under laboratory conditions the thermocouple as constructed would be applicable to general foundry conditions and requirements.

VI. PREPARATION AND MECHANICAL TESTS OF SPECIMENS

All of the various shapes cast in sand were machined down to the uniform length of $4\frac{1}{2}$ inches, with a center test section 0.505 inch diameter by 2 inches long, and fillets connecting the threaded ends $\frac{3}{4}$ inch diameter with the center section. Three points, 1 inch apart on centers, were established on the center section of each bar, from which to measure the elongation after stress.

Since the ninth series was poured in chill bars 13 inches long, it was possible to secure three test bars from each chill bar. These were turned down to a uniform diameter of about 1 inch, and cut into three pieces which were further machined down to the required dimensions.

Each bar was tested in an Emery hydraulic testing machine. Extensions were taken by an extensometer for increasing loads of 200, 500, 1000, 1500, 2000, 2500, 3000, 3500, and 4000 pounds.

After the 4000-pounds load the extensometer was removed from the bar and the stress continued up to complete destruction of the bar, the breaking load being recorded and the stress per square inch calculated from the dimensions of the section. Then the elongation on each part was measured and the sum of the two taken as the total elongation in 2 inches. The reduction in area at the point of fracture was taken by means of a micrometer.

VII. PHYSICAL PROPERTIES

All of the above-mentioned data were obtained for each specimen and the curves plotted from the information thus obtained, as shown in the Figs. 5, 6, 7, 8, and 9. While all of these physical properties have been plotted in consecutive sequence with reference to the temperatures at which the bars were poured, with the object of determining the effect of pouring temperature on the properties of the alloy, there appears to be, nevertheless, no simple relation readily deducible between the pouring temperature and the strength of the specimen.

1. GENERAL DISCUSSION OF RESULTS OF PHYSICAL TESTS.

The physical properties to be considered were the tensile strength, elongation, reduction of area, extensions under increasing loads from 200 to 4000 pounds, respectively, and the hardness and specific gravity. The test bars were cast as separate units and not as attached members to the body of a larger casting, for it is now admitted that for a copper tin alloy the attached test bar does not represent the strength of the casting as a whole and, in general, would be expected to give higher values than sections cut from the castings themselves. To show the relative values the metal is capable of giving, the various shapes were cast as separate units, with different methods of molding, and poured at various temperatures to ascertain, if possible, the best methods to be pursued in order to obtain uniform results. It has also been found by various experiments that when test bars were made of unequal sectional area, and the test members turned from the larger pieces, the interior possessed no skin and gave lower results. (See Webbert on "Specimens for non ferrous castings.")¹²

¹² Proc. of Amer. Soc. for Testing Materials.

It has also been found that owing to a lack of uniformity in the rate of cooling of the heavier bars (exceeding $\frac{3}{4}$ inch diameter) the physical results show considerable lack of uniformity. For these reasons the greatest number of experiments in this investigation have been made with specimens that have not had the external skin cut away very much in reducing them to the size required for testing. Another advantage of the smaller size and almost uniform section is that the shrinkage is more uniform and when such sections are properly gated there is less tendency to the production of internal strains, which would develop a weakness in the tested specimen, and thus lead to erroneous deductions.

It can be shown that the tensile strength alone of any given specimen is not an invariable criterion of its value, and the same deduction is true of the elongation and reduction of area; also that there is a closer relation and interdependence between the elongation and the reduction of area of a specimen than between any two other properties. A large elongation in a sand-cast specimen is generally accompanied by a corresponding increase in the reduction of area. In the tests made of the extensions under successive increasing loads the different bars showed no definite yield point except in a few limited cases, but wherever the stress-strain curve plotted was uniform in curvature the bar would show a uniformity of texture from which superior results might be expected. Wherever there is a sudden deviation from this uniformity of deformation it is probably due to some interior stress developed at that point by the load of deformation, as such specimens as a whole fail to reach the normal average of the bars of such a series. The conclusion to be derived from these results is that uniformity of curvature of the stress-strain curve is a safer guide to the homogeneity of the mass-structure than the so-called yield-point determination. It is known that once the yield point is attained further loading increases the elongation of the bar with more than normal rapidity.

It is well known from metallographic studies that during the cooling of an alloy from the fluid state, crystals separate out from the mother fluid, which possess a density different from that of the body of the fluid, and these heavier portions sink to the bottom. Such a phenomenon is known as liquation. This pheno-

menon is favored by a slow rate of cooling, hence the larger the sectional area of the test bar the less will be the probable homogeneity, and this fact is an additional reason for choosing the smaller section in the making of the test bar. The tendency to liquation is avoided by a thorough stirring of the molten bath before the bar is poured, followed by a rapid cooling, where such a procedure is possible. In test bars that show a uniform texture at the fracture but yield low tensile results, a metallographic examination of the fresh fracture will sometimes reveal tiny globules, or bright surfaces, which appear to fill up the interstices between the crystals; this appearance shows that some alloy phase of a melting point lower than the mother fluid has solidified last. This formation is always attended by results lower than normal, and is due first to inadequate stirring of the metal when compounded, or to too great a proportion of virgin metal, or to ineffective stirring just before the molten alloy is poured into the molds. It is not of frequent occurrence except when lead is a component of the prepared alloy.

From the chill bar, which presents the minimum elongation to be expected, with a given tensile strength, to the cast-to-size shape, cylindrical form, and so on, the larger the sectional area at the center of the piece for the same length of the specimen, the greater is the elongation that may be expected, but at the same time there is no factor from which, if one of the values be known, the other may be derived.

The chill-bar test is not representative of the alloy unless the bar be annealed or quenched. Poured from the same heat as the sand-cast specimen, its rate of cooling is more rapid, its density is greater, and its crystalline structure is not so open in texture as the sand-cast specimen, and for these reasons it is not comparable in the physical properties developed under stress to the sand-cast specimens.

In considering the physical properties of the chill-bar specimen it is well to remember that at rather low and very high pouring temperatures the chill bar represents the utmost tensile strength of which the metal is capable, and only on account of its sudden solidification is its corresponding percentage of elongation and reduction of area greatly lowered over what is expected of the sand-

cast specimen. This initial chill creates internal stresses and prevents the flow of the metal under continuous tensile stresses. In other words, the internal core of the bar is in an abnormal state; now if this state be normalized by restoring its internal structure to a condition of equilibrium at the surface with respect to stresses, by submitting such a chill bar to a proper heat treatment, either annealing or quenching after heating to a temperature

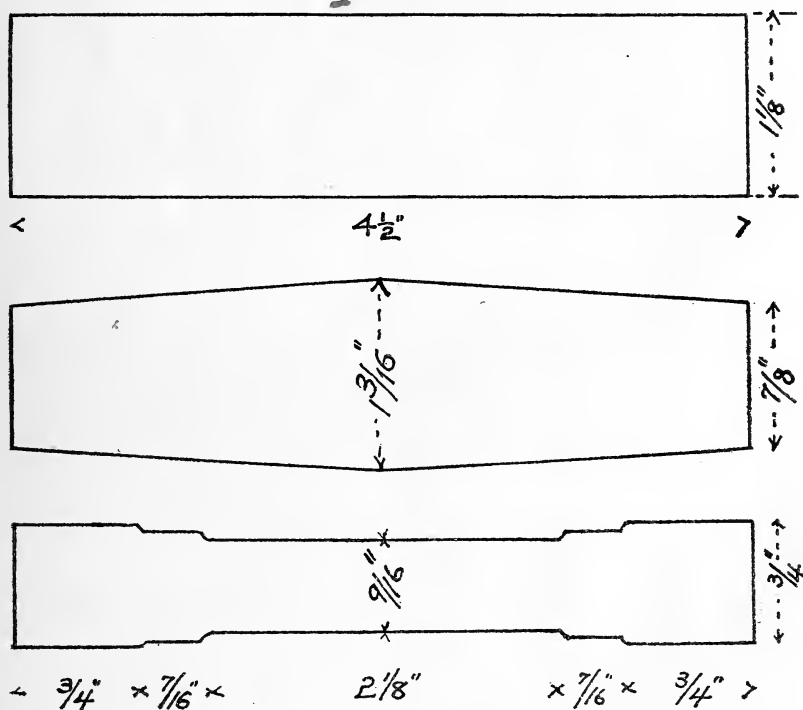


FIG. 3.—Patterns of test bars

of from 700° to 800°C (1292° to 1472°F) for 30 minutes, it will be found either in the properties of elongation or reduction of area or in the metallographic examination, that the microstructure has been normalized, and that the elongation and reduction of area have been increased by nearly 400 per cent, giving values equivalent to those of the best sand-cast specimen that can be obtained. In investigating a chill-bar specimen it would be advis-

able, therefore, to submit it to a proper heat treatment in order to restore the metal to its normal state and then to test it for its true physical properties, because the heat treatment recommended does not deform the specimen in any way nor does it alter its chemical composition.

The general results show that there is no proportionate ratio between elastic limit and tensile strength, but a more extended investigation of these properties of suitably heat-treated, zinc-tin bronzes may be able to establish such a relation.

Fig. 4 is a photograph of 14 specimens which shows their appearance after fracture; photomicrographs of fractures and sections of typical specimens are also shown in Part II.

Table 2 furnishes details of the shapes, pouring temperatures, method of molding, and physical properties.

TABLE 2

Test bar	Shape	Pouring temperature	Sand	Tensile strength		Elongation in 2 inches	Reduction of area
				Pounds per sq. in.	Kilograms per cm ²		
		°C				<i>Per cent</i>	<i>Per cent</i>
531.....	A	1200	F. G. S.	45 700	3213	24.5	20.0
591.....	B	1200	F. G. S.	40 500	2847	24.5	23.0
609.....	C	1220	F. D. S.	37 800	2657	25.0	23.0
637.....	A	1200	F. D. S.	45 000	3164	21.5	18.0
648.....	B	1120	F. D. S.	39 300	2763	17.5	17.0
704.....	B	1220	V. G. S.	41 800	2939	29.0	24.0
707.....	D	1220	Chill	49 700	3494	6.0	7.0
740.....	A	1225	V. G. S.	49 600	3487	30.5	19.1
802.....	A	1180	V. G. S.	49 100	3452	36.0	33.7
814.....	A	1255	F. D. S.	50 500	3550	53.0	40.3
905.....	D	1120	Chill	49 300	3466	5.5	4.0
923.....	A	1255	F. D. S.	35 600	2503	16.0	15.0
1015.....	A	1270	V. D. S.	29 300	2060	9.5	16.9
1020.....	A	1270	V. D. S.	42 500	2988	18.5	20.2

[Shapes: A=cast to size, B=cylindrical, C=barrel, D=chill. Sand: F. D. S.=poured flat in dry sand, F. G. S.=poured flat in green sand, V. D. S.=poured vertical in dry sand, V. G. S.=poured vertical in green sand, Chill=poured in open iron chill mold]

By referring to the table it will be noted that in specimens 531 and 591 the elongation was identical, but there was a difference in their reductions of area and tensile strength in which the cast-to-size shape exceeded the cylindrical shape by over 5000 pounds

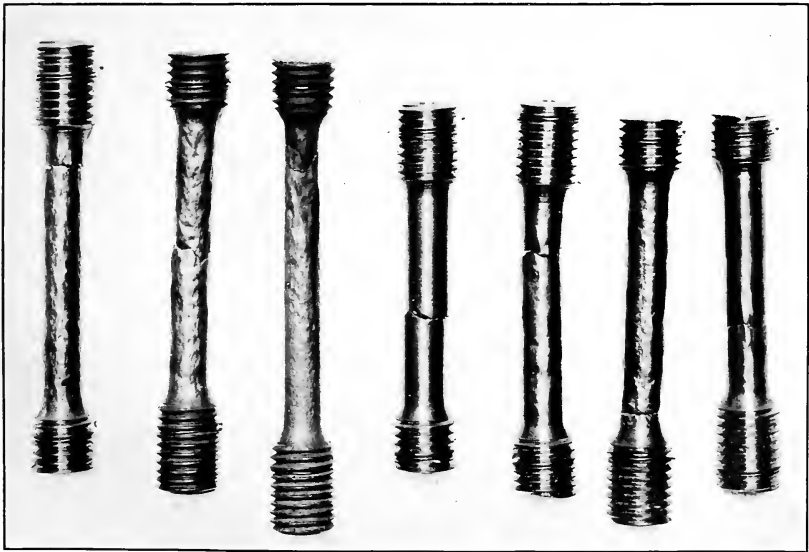
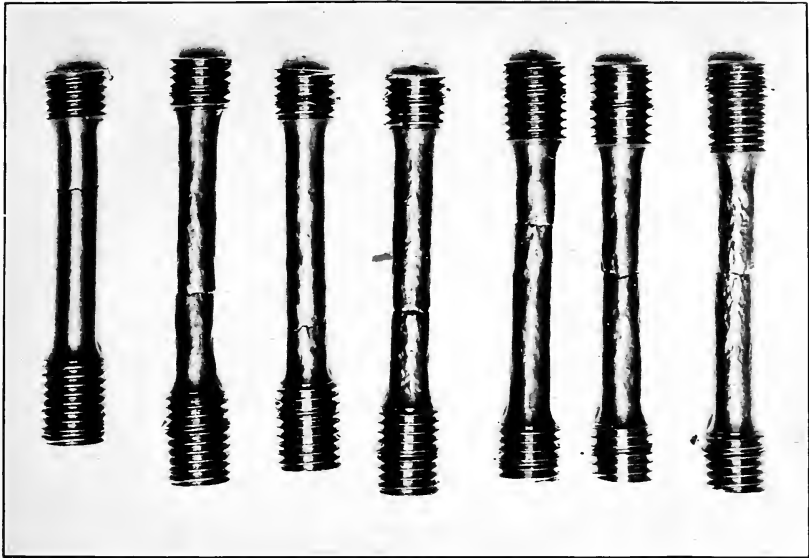


FIG. 4.—*Fractured test bars*



per square inch. Although not poured at the same time from the same heat, the comparison is a fair one, because both were poured at the same temperature. It is probable that where every other condition is the same the cylindrical shape will yield a specimen from which might be expected a higher relative elongation in proportion to its tensile strength than could be obtained from the cast-to-size shape.

In the three shapes representing the sixth series the barrel-shape specimen shows its superiority in elongation and reduction of area to either of the other shapes, but, as might be expected, was inferior in tensile strength.

In the sand-cast specimens representing the seventh series the same relative high percentage of elongation in proportion to tensile strength is shown by the cylindrical specimen.

The eighth series consists entirely of specimens which have been submitted to heat treatment. (See Sec. VIII.)

The two specimens from the ninth series stand at the beginning and the completion of the zone of favorable pouring temperatures, and the results obtained may be considered as representative. Both were poured from ingot metal made from turnings of previously prepared specimens and contained no virgin metal.

The two specimens from the tenth series were poured at the same temperature but in different heats. Both show great uniformity of extension from the initial to the ultimate load. The great difference in the values obtained is probably explainable by the inclusions of oxide segregations or the presence of inclosing oxide films about adjacent crystals, which would lessen their tensile strength.

The chill bars 707 and 905, respectively, exhibit the characteristics of all the test bars poured in this series of tests, viz, a low elongation and reduction of area corresponding to a high tensile strength.

(A) *Comparison With the Work of Other Investigators.*—In some tensile tests of this same type of zinc bronze recently reported to the American Society for Testing Materials Mr. Webbert found for eight tests an average tensile strength of 38 866 pounds per square inch and 25.3 per cent elongation; the pouring temperature

was found to be 1120° C (2048° F), but his alloy contained 1 ounce of 15 per cent phosphor copper for every 100 pounds of alloy. While it is not known exactly how much such an addition of phosphor copper will increase the tensile strength of such an alloy, it is well known that other conditions being the same it would produce a marked increase of the tensile strength and of the elongation.

The same alloy made by H. S. and J. S. G. Primrose, cast in dry sand, had a tensile strength of 38 528 pounds per square inch and an elongation of 24 per cent, whereas the 18 specimens cast flat at the Bureau in dry sand at about the same temperature, 1175° C, had an average tensile strength of 40 148 pounds with an elongation of 20.3 per cent and a reduction of area of 18.3 per cent. Neither in Primrose's nor in the latter specimens was there any phosphor copper used. It should also be noted that in the latter specimens some 20 to 25 per cent of remelted gates, sprue heads, and clean floor spillings were used, which would have a tendency to reduce the percentage of elongation and reduction of area obtained without materially lowering the tensile strength.

Primrose's specimens were cylindrical in shape, 10 inches long by 1 inch diameter; some portion of the chilled surface was cut away in reducing the specimen to the size required for testing, and the fact that they were 10 inches long as against our 4½ inches might increase his percentage of elongation. By affording the strain an opportunity to be more evenly distributed would also tend to increase the elongation.

As an illustration of what a similar bar may do, one of the same shape as his poured at a temperature of 1200° C (2192° F) flat in green sand showed a tensile strength of 40 500 pounds per square inch, an elongation of 24.5 per cent, and a reduction of area of 23 per cent. An average of these 10 tests shows that it is possible to obtain a tensile strength of about 39 000 pounds per square inch, with a corresponding elongation of 25 per cent, if only virgin ingot metal is used in making the alloy.

The bar represented by specimen 1015 shows a result below the normal. This was the first bar cast in the third flask of the heat, the bars cast in the same flask giving an average tensile strength of

34 600 pounds per square inch, an average elongation of 12.3 per cent, and an average reduction of area of 20.5 per cent. This heat, as its series number indicates, was poured entirely from old gates, sprue heads, and floor spillings, and contained no new metal. It was, therefore, poured purely as a "remelt" test, and, as the temperature of pouring was 1270° C (2318° F), rather high for a "remelt" series of tests, the low result in elongation and reduction of area is readily accounted for.

The bar represented by specimen 1020 was cast in the fourth flask of the same series, and poured at the same temperature as No. 1015, but was the last one of the series to be poured. The average result of the three bars in that flask was 38 900 pounds per square inch, 17 per cent elongation, and 18.6 per cent reduction of area. As the temperature of pouring when the fourth flask was reached was considerably lower than that at which the third flask was poured, it is evident that the elongation and reduction of area were influenced by the temperature at which the specimens were poured. To carry the comparison still further, the specimens poured vertically in dry sand from the same pot of metal, and at virtually the same pouring temperature, show in all the physical properties superior results to the specimens poured flat in dry sand.

2. EFFECT OF MANNER OF MOLDING

Fig. 5 consists of two diagrams, one showing the results of the tensile tests of the cast-to-size shape arranged according to the various methods of molding previously described. In the casting temperature zone favorable to all methods the bars cast vertically in dry sand show the greatest uniformity of results, because no doubt variables of sand conditions were less than in other methods. This is due doubtless also to the more rapid filling up of the mold in pouring and to lack of cold shuts in the casting; also to the greater freedom with which the gases evolved in pouring freed themselves from the falling column of molten metal. The second diagram shows the results of the tensile tests for each shape but with all methods of molding combined. Through the favorable range of casting temperatures for all specimens the cast-to-size shape is unmistakably superior to all other shapes in its high range

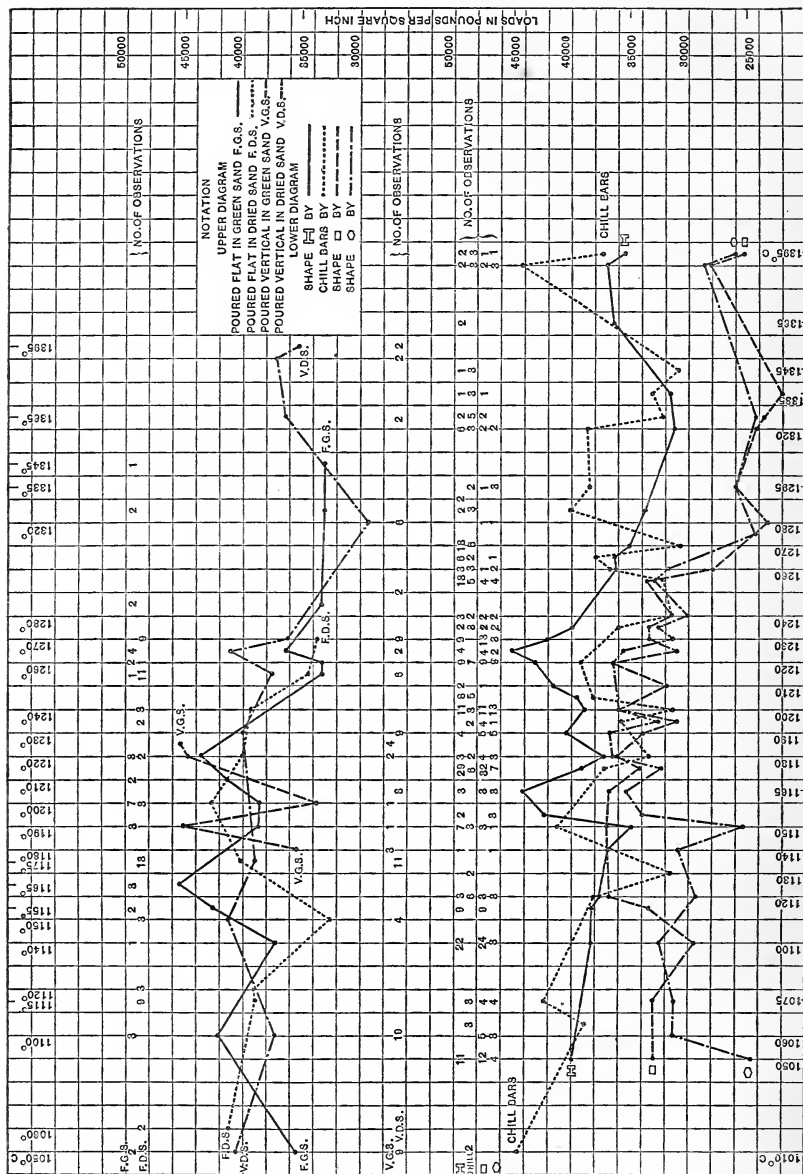
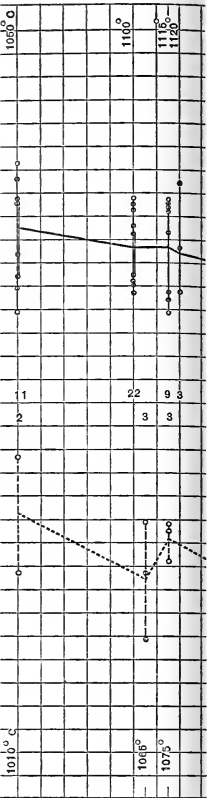


FIG. 5



Fold-out Placeholder

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future date.



INCLUSIVE

CHILL CAST

ALL TESTS IN ABOVE DIAGRAM WERE MADE FOR SAND CAST SPECIMENS OF THE SHAPE [A] ALL ANNEALED INDICATED BY "A" ALL QUENCHED INDICATED BY "Q" ALL CHILL CAST BARS INDICATED BY [Q]

and comparative uniformity of results. The results for the cylindrical and barrel shapes were also very uniform and ran very closely parallel. As shown in this diagram, the chill bar, on the whole, appears to be superior in strength to the two latter shapes as cast in sand.

Fig. 6 consists of two diagrams showing the results of tensile tests of the cast-to-size shape and the chill bar. The chill bar has a tendency to both high tensile strength and ductility at both the lower and higher range of casting temperatures and shows some uniformity of results in the favorable casting zone of temperatures 1120° to 1270° C (2048° to 2318° F).

Fig. 7 consists of three diagrams, the upper one showing the elongation in 2 inches of all shapes, the middle one the reduction of area of the same, and the lower one the range of the tensile strengths of the cylindrical and barrel shapes at all temperatures poured, together with the number of tests made at each temperature. It is noticeable, as might be expected, that the elongations of the chill bars at all temperatures except the highest, omitting the last one, fall much below those of the sand-cast specimens, although maintaining a uniformity, which shows by comparison that sand casting itself produces irregularities which are exceedingly difficult to account for. From the tests of reduction of area similar conclusions may be drawn.

In the comparison of the range of tests—that is, from low to high tensile strength—between the cylindrical and barrel shaped types the former shows some superiority, although slight, especially as to uniformity, but both agree in falling below the normal average at the high temperatures. This result is due no doubt to the greater oxidation and loss of material by vaporization than when poured at the lower temperatures. This is confirmed by the results of the microscopic studies. (See Part II.)

3. CHARACTERISTICS OF TYPICAL SAMPLES

Table 3 contains the results of the chemical analysis, density, and other physical properties of further typical samples. As a rule, the larger the percentage of tin contained the denser the alloy, and likewise the tensile strength appears to be greater with the denser specimens.

TABLE 3

Characteristics of Typical Samples

Shapes: A=cast to size, B=cylindrical, C=barrel, D=chill cast. Sand: F. D. S.=poured flat in dry sand, F. G. S.=poured flat in green sand, V. D. S.=poured vertically in dry sand, V. G. S.=poured vertically in green sand, chill=poured in chill mold. Density=grams per cubic centimeter.]

Test bar	Shape	Sand	Pouring temperature	Chemical analysis			Tensile strength		Elongation in 2 inches	Reduction of area	Density
				Cu	Sn	Zn	Pounds per sq. in.	Kilo-grams per cm ²			
			° C						Per ct	Per ct	
19	A	F. G. S.	1155	88.0	10.2	1.8	48 050	3378	26.0	20.0	.....
213	A	F. D. S.	1060	88.7	9.3	2.0	43 550	3061	30.0	30.5	.....
394	A	V. D. S.	1050	87.8	10.35	1.95	42 270	2972	20.5	13.5	8.519
430	A	V. D. S.	1175	86.96	10.91	2.13	41 900	2946	14.0	16.0	8.590
561	C	F. G. S.	1190	87.15	10.0	2.85	39 700	2791	31.0	24.5	8.378
605	A	F. D. S.	1220	87.03	10.42	2.55	39 900	2805	17.0	16.2	8.576
705	A	V. G. S.	1220	87.03	10.40	2.57	46 100	3241	29.0	22.6	8.777
810	A	{ V. G. S. V. D. S. }	1120	86.67	10.63	2.70	44 000	3093	20.5	14.0	8.730
929	A	V. D. S.	1255	86.85	9.97	3.18	39 800	2798	15.5	13.0	8.471
1011	D	Chill	1255	87.29	9.65	3.06	34 000	2390	15.0	12.1	8.618

No appreciable quantities of chemical elements other than those indicated were detected.

One representative sample has been chosen from each series, bearing in mind the necessity of representing the pouring temperatures from the lowest to almost the highest in what has been found to be the zone of temperatures favorable to the securing of representative types. It should also be remembered that the ninth series is poured entirely from turnings. The tenth series is poured from old gates, sprue heads, and floor spillings and is purely a "remelted" metal.

The percentages of copper, tin, and zinc, which are found in the analyzed metal, give an indication of the uniformity and exactness with which this alloy can be expected to be made up from new metal containing no scrap under the various molding and casting conditions. The samples for density were taken from portions of the sample not subjected to stress. It is seen that the density ranges from 8.378 to 8.777 and the slight variations appear to be associated with the tin content.

4. ELASTIC LIMIT

An examination of Fig. 6 shows that there is no sharp break in the stress-strain curve, and that the deformation of the bar takes place so gradually and as a rule so uniformly that the yield point is difficult to locate, but from the deformations indicated it may be shown that this limit ranges from 15 000 to 17 000 pounds per square inch. The specifications of the Bureau of Steam Engineering, United States Navy, for a bronze of this description require a minimum yield point of 15 000 pounds per square inch. As an illustration of what a good specimen can show, attention is called to test bar 357, which showed a definite yield point under a load of 4000 pounds, equivalent to a stress of 20 000 pounds per square inch. Many specimens having remarkably good physical properties show a definite high yield point, but in general this point can not be defined with any great degree of accuracy.

5. MELTING AND CRITICAL RANGES

The thermal curves are by the inverse rate method of Osmond in which the times required for the specimen to rise or fall equal temperature intervals are noted in terms of the temperature or $dt/d\theta$ vs. θ . But instead of using equal temperature intervals, equal emf intervals were used, corresponding to approximately 2°C . The specimens, turned down to about 10 mm diameter and 25 mm length, were tested in vacuo in a specially designed and automatically regulated electric resistance furnace.¹³ The emf intervals were measured with a platinum, platinum-rhodium thermocouple and a potentiometer, and the time intervals were measured to 0.1 second on a cylindrical, motor-driven Geneva chronograph.

Table 4 gives the results to the nearest 1°C and are probably accurate to better than 5°C . It is seen that the melting point, about 980°C (1796°F), is preceded by a transformation of considerable magnitude at 780°C (1436°F), and by a minute one at 530°C (986°F), which last is apparently suppressed sometimes after the first heating. The first corresponds to the final freezing

¹³ Bureau of Standards Scientific Paper No. 213, Burgess and Crowe.

and separation of the beta constituent, the second corresponds to the transformation of beta into alpha + delta. There appears to be no evidence of a third transformation in this alloy.

TABLE 4
Location of Maximum of Critical Ranges in Degrees Centigrade

Sample	Run	Heating			Cooling			
424.....	1st....			845				
424.....	2d....			<i>a</i> 847				
424.....	1st....	528		843			787	
424.....	2d....			<i>a</i> 847		<i>b</i> 799-785		
490.....	1st....	530		792			789	
490.....	2d....	526		<i>c</i> 790			789	
9.....	1st....	530		792			787	
9.....	2d....	<i>d</i> 529		<i>c</i> 790			787	
19.....	1st....	526		844				
19.....	2d....	(<i>e</i>)		844				
422.....	1st....	518	<i>f</i> 781	836	<i>g</i> 978	<i>h</i> 981	817	776 504
422.....	2d....	516	781	<i>b</i> 808-832	982	978	(<i>e</i>)	775 504
380.....	1st....		781	898		<i>h</i> 993		785

a Not so well defined as on first run.

b Double cusp.

c Smaller than on first run.

d Very small.

e Disappears after first run.

f Small on first run up.

g Melting point.

h Freezing point.

The physical properties of the specimens submitted to thermal analysis are as follows:

No. 424 was a cast-to-size shape bar, poured at a temperature of 1175° C (2147° F). It had a tensile strength of 45 000 pounds per square inch, a yield point, determined by the drop of the beam, of 19 600 pounds per square inch, an elongation in 2 inches of 19 per cent, and a reduction of area of 13.5 per cent.

No. 490 was a cylindrical-shaped bar, poured at a temperature of 1390° C (2534° F). It had a tensile strength of 14 000 pounds per square inch, a yield point (by drop of beam) of 4500 pounds per square inch, an elongation in 2 inches of 1 per cent, and a reduction of area of 0.5 per cent. Examination of the structure exhibited a highly oxidized mass of crystals and the micro-structure showed that the brittle eutectoid rich in tin had not been absorbed in the alpha solution but was prominently visible

and interspersed through the alpha constituent, hence the low tensile strength of the specimen.

No. 422 was a barrel-shaped specimen, poured at a temperature of 1175° C (2147° F). It had a tensile strength of 32 000 pounds per square inch, an elongation in 2 inches of 11 per cent, and a reduction of area of 10 per cent.

All of the above specimens were poured vertically in dry sand.

No. 380 was a cast-to-size shape bar, poured at a temperature of 1100° C (2012° F). It had a tensile strength of 38 500 pounds per square inch, a yield point of 18 000 pounds per square inch (by drop of beam), an elongation in 2 inches of 15.5 per cent, and a reduction of area of 11.5 per cent. Its microstructure showed an almost complete absorption of the tin-rich eutectoid in the alpha solution. It was poured vertically in dry sand.

No. 19 was a cast-to-size shape bar, poured at a temperature of 1155° C (2111° F). It had a tensile strength of 48 050 pounds per square inch, a yield point (by drop of beam) of 29 300 pounds per square inch, an elongation in 2 inches of 26 per cent, and a reduction of area of 20 per cent. The microstructure shows an almost perfect crystalline formation, with the tin-rich eutectoid almost completely absorbed in the alpha solution, and the dendritic crystals uniformly distributed. It was poured flat in green sand.

No. 9 was a large size cylindrical bar, 2 inches in diameter, poured at a temperature of 1140° C (2084° F). It had a tensile strength of 17 000 pounds per square inch, an elastic limit of 14 500 pounds per square inch, and an elongation in 2 inches of 1 per cent; reduction of area not recorded. The microstructure showed various holes which indicated inequality of shrinkage during cooling and the formation of two different solutions which had separated out in the slow cooling of the mass, which promoted the separation out of the tin-rich eutectoid and thus caused the low tensile strength of the specimen. It was poured flat in green sand.

VIII. HEAT-TREATED SPECIMENS

The eighth series cast was devoted to tests of the action of annealing and cooling slowly, and annealing followed by quenching, in which the bars were submitted to temperatures of 500°,

600°, and 700° C (932°, 1112°, and 1292° F). The tensile strength was not materially affected by such treatment, but as to ductility there was great increase in elongation and corresponding reduction of area after submitting the samples to temperatures between 600 and 700° C (1112° and 1292° F). Fig. 9 shows graphically the results of such treatment. In the case of annealed bars superior results were obtained both for sand cast and chill cast bars in the temperature range from 700 to 800° C (1292° to 1472° F). In the quenched bars, sand cast, superior results were obtained in the temperature range from 600° to 700° C (1112° to 1292° F). With annealed bars the results agree very well with those obtained by H. S. and J. S. G. Primrose¹⁴ but with the results obtained from the quenched bars are not concordant with theirs.

No. 802 (see Fig. 4) was heated to 700° C (1292° F) and held at this constant temperature for 30 minutes in a gas muffle furnace and then allowed to cool in the muffle for 24 hours to room temperature. The eutectoid, indicated in a few places by minute white crystals, has been almost completely absorbed by the alpha or copper-rich constituent during the annealing. This in turn has recrystallized for a depth of $\frac{1}{16}$ inch on the outside of the specimen. The large increase in the elongation and reduction of area is probably due to the absorbed solution of the eutectoid rather than to the recrystallization.

No. 814 (see Fig. 4 for appearance of specimen after fracture) was poured flat in dry sand at a temperature of 1255° C (2291° F), cast-to-size shape, heated to 700° C (1292° F), held 30 minutes at that temperature, and cooled in furnace for 24 hours. The surface layer appeared to be well annealed, the annealing extending in for a distance of $\frac{1}{16}$ inch. The microscopic examination shows the metal to have been completely recrystallized into the characteristic polyhedral crystals of bronze.

A study of the specimens submitted to heat treatment in comparison with others which have not been subjected to such treatment show that due either to recrystallization or to the absorption of the beta formation by the alpha formation to form one solid homogeneous solution there is a marked increase in the values of

¹⁴ Jour. Inst. of Metals, 1913, p. 164.

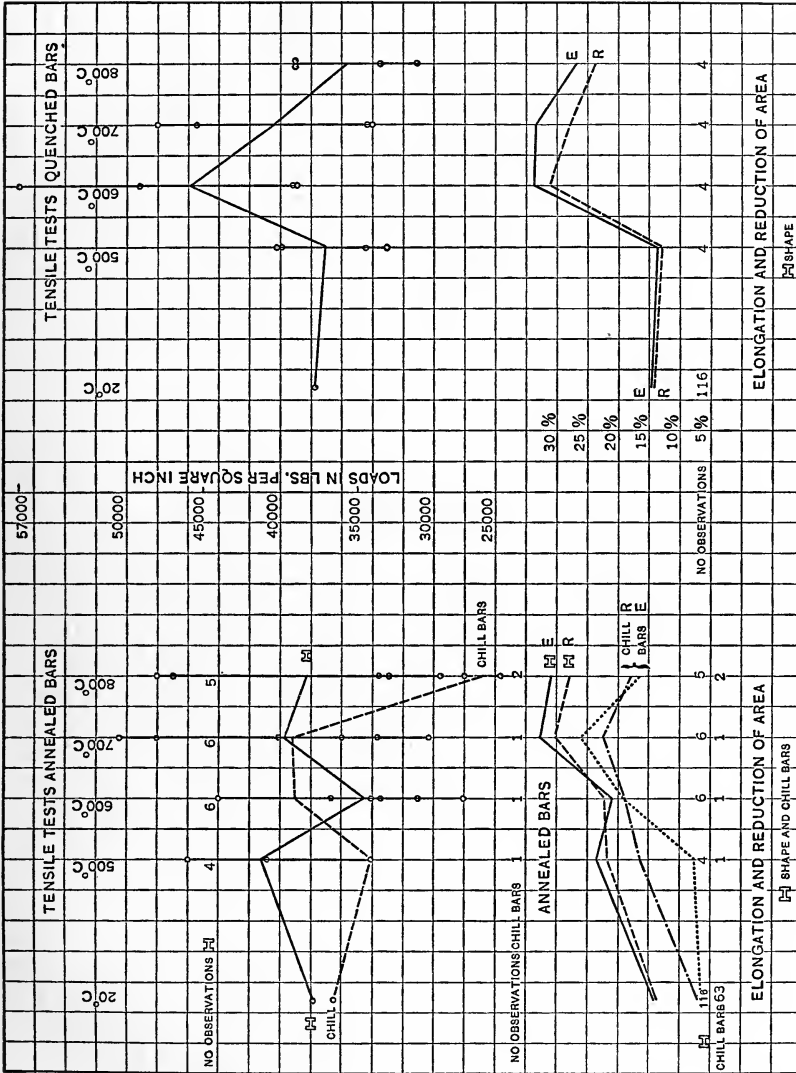


FIG. 9.—Heat-treated test bars

the elongation and the reduction of area without a change of any magnitude in the tensile strength. The removal or absorption of the brittle constituent seems to make the bars so treated much more uniform in their physical properties and would indicate by analogy that commercial castings themselves when submitted to such treatment, where such treatment is feasible, would be greatly improved in character. It is also surmised that such treatment would tend to protect such castings from hydraulic failure by closing the grain and lessening the interstices or voids between the crystals and by limiting the crystallization to a form and compacting the mass of crystals to an extent which would render them less susceptible to hydraulic failure. Experiments are to be conducted in the near future to test the truth of the hypothesis.

IX. CHOICE OF TEST SPECIMENS

In general, the test piece should correspond to the type of casting so as to be representative of the principal physical properties of the latter.

Where it is desirable to obtain a knowledge of the physical properties of a casting made in sand, the test bar should be cast in sand, at approximately the same time and from the same heat. Judging from the experiments made at the Bureau it is possible to secure specimens cast to size in sand and poured within a range of temperatures from 1120° to 1270° C (2048° to 2318° F), which will have a tensile strength of 37 000 pounds per square inch, an elongation of 15 per cent in 2 inches, and a reduction of area of 14 per cent; and under regular foundry practice, using similar materials and under similar conditions, such a test bar might be expected to have a tensile strength of 33 000 pounds per square inch, an elongation of 14 per cent in 2 inches, and a reduction of area of 13 per cent. But if a bar of similar character be submitted to heat treatment—that is, heated at 600° C (1112° F) in a furnace for 30 minutes and quenched or allowed to cool in the furnace to normal temperature—it might be expected to show a tensile strength of 36 000 pounds per square inch, an elongation of 25 per cent in 2 inches, and a reduction of area of 24 per cent.

The properties of a chill bar are not those of the casting, but can be made to approach it very closely by proper heat treatment;

but if the casting is to be made in a chill mold, the test bar corresponding to the same heat should also be made in a chill mold, preferably an open one, as in accord with ordinary foundry practice. The tensile strength of a chill-cast bar is not favorably influenced by heat treatment, but its ductility is considerably increased; so that if a chill-cast bar first be annealed or quenched at a temperature of about 600°C (1112°F) so as to restore its crystalline structure to a state resembling that of the sand-cast specimen, there may be expected of it a tensile strength of 30 000 pounds per square inch, an elongation of 16 per cent in 2 inches, and a reduction of area of 15 per cent, which closely approximates that of the sand cast-to-size bar not heat treated. The chill bar so treated may properly be referred to as a normalized chill bar.

The heat treatment of such bars may be performed in a simple manner, by making use of a gas muffle furnace, in which the bars are placed and heated for 30 minutes to a temperature of 600°C (1112°F), measured by a thermocouple pyrometer, and either allowed to cool down in the furnace for 24 hours to normal temperature or immediately quenched.

X. SUMMARY AND CONCLUSIONS

1. The best type of test bar where the metal is to be cast into sand is the cast-to-size shape. If the metal be poured within the range 1120° to 1270°C (2048° to 2318°F), greater uniformity of tensile strength and ductility may be secured.

2. It was anticipated at the beginning of these investigations that some one temperature would be found at which the best and most uniform results as to the two important physical properties—tensile strength and ductility—would be obtained, but the series of tests showed that instead of one such temperature there was a zone of temperatures, viz, 1120° to 1270°C (2048° to 2318°F), at which good results might be expected anywhere within that favorable zone of pouring temperatures.

3. The kind of mold to be recommended is a dry-sand mold, which should be poured either flat or vertical. The first method is more economical of time and labor, but has, however, no superiority over the vertical pouring in the matter of technical results.

4. The results of the chill and best sand cast test bar are of almost equal value if the chill bar be annealed at temperatures ranging from 500°C (932°F) to 700°C (1292°F), but otherwise the former is inferior to the sand cast-to-size shape as a representative test bar.

The advantages of the chill bar are that there are no molding requirements and that it can be poured by unskilled labor. Its disadvantages are that it is expensive to machine into shape and size required for testing, and it gives results both as to tensile strength and ductility that are misleading.

The advantages of the cast-to-size shape are that it is easy to mold and inexpensive to machine into the shape and size required for testing. From the results obtained it is believed to be the form which should be adopted as standard for general foundry practice.

5. Heat treatment is productive of increased ductility, and has a marked effect on the deformation produced by continuously increasing loads on specimens annealed in the temperature zone of 600°C (1112°F) to 700°C (1292°F), which is in accord with the results of other observers.

6. As an alternative for the sand-cast specimen, if one prefers to work with a chill-cast specimen, as is the case in some foundries, the results show for the few observations taken that when annealed between a temperature range of 500°C (932°F) to 700°C (1292°F) a normalized chill bar is secured which is comparable to the sand cast-to-size shape. The specimens annealed and quenched offer no appreciable superiority to the specimens annealed and cooled slowly.

7. The average density of sand-cast specimens is about 8.58 and of chill cast about 8.6.

8. The elastic limit of this zinc bronze varies from 15 000 to 17 000 pounds per square inch.

9. The cooling curves show that the melting point of the alloy is about 980°C (1796°F) and that there is a pronounced transition point at 780°C (1436°F) and another feeble one at 530°C (986°F).

10. In Table 5 is recorded a summary of all the results obtained for physical properties arranged in terms of the type of casting.

TABLE 5
General Averages of all the Observations Taken

Number of bars.	Shape	Tensile strength		Elongation in 2 inches	Reduction of area
		Pounds per square inch	Kilogram per square centimeter		
217	Cast to size.....	37 869	2662	Per cent 15.5	Per cent 14.7
161	Cylindrical.....	32 832	2308	14.9	13.9
95	Barrel.....	32 029	2252	14.2	13.8
88	Chill cast.....	36 512	2567	6.3	6.9
21	Sand cast, annealed.....	38 190	2685	27.0	26.0
16	Sand cast, quenched.....	39 810	2798	26.9	24.2
5	Chill cast, annealed.....	31 160	2190	17.0	16.7

In all of the above it is to be borne in mind that only pure copper, tin, and zinc have been used, and the results obtained are characteristic of variations in foundry practice on virgin metal only once or twice melted except as noted in the text. The presence of scrap containing small amounts of lead, manganese, iron, and other ingredients which might influence the results of the tests with a standard bar are thus eliminated.

11. As a supplement to these experiments, there is being carried out under the auspices of the advisory committee on nonferrous metals to the Bureau of Standards a series of comparative foundry tests by several members of this committee in cooperation with the Bureau of Standards, using identically prepared metal ingots, prepared by one of the committee, to determine what uniformity of results may be obtained by different founders in the preparation of test specimens of this alloy as judged by the usual physical tests.

For the work above described, the physical determinations were made by R. P. Devries and E. L. Lasier; the microscopic examinations by H. S. Rawdon; and the thermal analysis by J. J. Crowe, and to all of these gentlemen the author is deeply indebted for their interest and cooperation in this investigation. The foundry operations were carried out in the Pittsburgh laboratories of the Bureau of Standards, and here also the very considerable labor of preparing the test pieces was executed.

WASHINGTON, March 27, 1915.

APPENDIXES

Appendix A.—SUGGESTED SPECIFICATIONS FOR THE PREPARATION OF STANDARD ZINC BRONZE (Cu 88, Sn 10, Zn 2) TEST BARS

MIXING AND MELTING

Weigh out the required quantities of electrolytic copper, Straits tin, and Horsehead zinc.

Cover the bottom of the crucible with pieces of charcoal about the size of a hickory nut. Put in all the copper the crucible will hold, and cover the surface with small pieces of charcoal (no dust). Should the crucible not have the capacity to contain all of the copper charge, heat the charge contained until one or two of the pieces of copper are melted, crowd the remainder down into the molten mass, and add the remaining copper, bring the whole charge into a molten state, then add the tin, stirring the whole thoroughly with an Acheson graphite rod stirrer, and after previously heating the zinc, add the amount of zinc weighed out and stir thoroughly. Keep the pot covered with a graphite cover during the melting period. After adding the zinc allow the whole charge to come to a good melting heat, denoted by the play of zinc flames over the surface or at the edge of the surface adjoining the crucible. Remove the pot from the fire and take the pouring temperature with a thermocouple. Pour the metal at any temperature between 1120° and 1270° C (2048° and 2318° F), but note the temperature at which the bars are poured. Use P-Pt Ir or P-Pt Rh (10 per cent) thermocouple protected by a fused silica tube or an equivalent pyrometric method of determining the pouring temperature. When using platinum-rhodium couples add five-tenths of the temperature recorded at the cold junction to temperature reading of millivoltmeter for the corrected pouring temperature, or 0.75 when using a platinum-iridium couple.

MOLDING

Use any good molding sand equal to Albany No. 2. If green sand be used, the moisture content should not exceed 12 per cent. If dry sand be used, face the mold with a layer of sand equal in fineness to No. 00 Crescent sand, tempered with molasses water. When the mold is finished spray the molds and runners and pouring gate with molasses water, and dry each flask before the drying oven until the deepest pattern or feeding gate is completely dry. Allow the mold to cool to room temperature before being poured. Pick the vent holes with a fine needle in every one of the bulb reservoir feeders.

GATING

Put not less than three patterns of cast-to-size shape in each flask, gated as shown in Fig. 1, c.

POURING

Skim the pot carefully before pouring and hold back dross and scoriæ with the skimmer as much as possible before pouring. Pour steadily with a stream that will just about half fill the runner, and not large enough to choke the bore of the runner, so as to allow the bulk of the gases carried down by the pouring stream to escape upward through the space left in the runner and the pouring head. With every heat pour a wedge-shaped chill bar about 13 inches long by $1\frac{1}{2}$ inches deep by $1\frac{1}{2}$ inches wide on top. Always pour the chill bar nearly flat and from the same end. Each chill will make three test bars. Always begin the numbering of the chill bars from the pouring end.

The size of the cast specimen in the rough should be $4\frac{1}{2}$ inches long, $\frac{5}{8}$ inch diameter at center, and $\frac{13}{16}$ inch diameter at threaded ends.

The size of the finished specimen should be, length over all, $4\frac{1}{2}$ inches, length of center section 2 inches between gage points, size of threaded ends $\frac{3}{4}$ inch diameter by 1 inch long, length of each fillet $\frac{1}{4}$ inch, diameter of center section 0.505 inch.

Appendix B.—COMPARISON WITH NAVY SPECIFICATIONS

The Navy specifications call for a tensile strength of 30 000 pounds per square inch and an elongation of 15 per cent. A comparison of the tests of the zinc-bronze bars with these requirements are shown in the accompanying table.

TABLE 6

	Percentage of bars meeting Navy requirements	Percentage of the remainder coming within 10 per cent of same	Percentage meeting only requirements of tensile strength
Cast in sand:			
Cast-to-size shape.....	53.0	27.0	89.8
Cylindrical shape.....	52.8	27.7	73.3
Barrel shape.....	42.1	10.0	66.0
Cast-to-size shape annealed.....	100.0		
Cast-to-size shape quenched.....	100.0		
Cast in chill mold:			
Chill bar.....	4.5	1.0	87.5
Chill bar annealed.....	100.0		

If one considers the tensile strength alone, it will be found that all of the test shapes and methods might be considered satisfactory, but the requirements for elongation are so rigid that only when the bar or the casting to which it refers is submitted to heat treatment is one able to meet these requirements; also this treatment restores the metal to its natural state and true condition and thus develop fully the physical properties of which it is capable.

If we study the effect of heat-treating test bars at the various temperatures of 500°, 600°, 700°, and 800° C (932°, 1112°, 1292°, and 1472° F), for a period of 30 minutes, followed either by slow cooling in the muffle furnace to normal temperature or by

quenching in water, it is found that, whereas the tensile strength is not greatly increased, the elongation and reduction of area are increased to a remarkable extent. The range of temperature from 700° to 800° C (1292° to 1472° F) appears to be the most favorable in securing the greatest increase in such properties.

In order to write a specification for the physical properties of a zinc bronze that would not be too difficult of fulfillment, without detriment to the public service, it is necessary to consider what may be reasonably expected of such a metal alloy as zinc bronze. It may readily be seen from the experimental work cited that a tensile strength of 30 000 pounds per square inch is not an unreasonable requirement.

With reference to the elongation desired, it is found that 15 per cent is difficult to obtain for specimens that represent small castings, because such castings, owing to their small sectional area, receive an initial chill which materially lowers the amount of possible elongation, and for such a casting the cast-to-size shape, on account of its relatively small sectional area, is naturally a representative type of test bar and should be chosen, but it is open for consideration whether 15 per cent elongation for such a specimen is not too severe to be expected in the course of ordinary practice. In all probability 14 per cent elongation and 13 per cent reduction of area is all that may reasonably be expected for this alloy when the casting to be tested has a large sectional area in proportion to its mass. If the sample be poured within the normal range of temperatures—that is, from 1115° to 1260° C, inclusive (2039° to 2300° F)—the tensile strength of 30 000 pounds per square inch is not difficult to secure, and it is possible in a majority of cases to obtain an elongation of 15 per cent and a reduction of area of 14 per cent, and for such castings a cylindrical shape may be chosen.

If a casting is to be chill cast, while it is very easy to secure a tensile strength of 30 000 pounds per square inch, it is, on the other hand, impossible to secure an elongation of 15 per cent; in fact, an elongation of 4.5 per cent would be a fair equivalent for such a casting.¹ This is because the initial stress is so great as to almost completely destroy the property of elongation. Now, if a chill bar is submitted to a proper heat treatment, either annealing or annealing and quenching as above described, it is quite possible to obtain and reasonable to expect an elongation of 15 per cent.

Hence from the above considerations it is fair to conclude that for small castings a tensile strength of 30 000 pounds per square inch with an elongation in 2 inches of 14 per cent and a corresponding reduction of area of 13 per cent may be required when using a cast-to-size shape test bar; for large castings, 30 000 pounds per square inch tensile strength, 15 per cent elongation in 2 inches, reduction of area 14 per cent; for chill castings, untreated, 30 000 pounds per square inch tensile strength, elongation 4.5 per cent, reduction of area 4 per cent; and for chill castings, heat treated, the same tensile strength, an elongation of 15 per cent, and a reduction of area of 14 per cent.

Appendix C.—AMERICAN SOCIETY FOR TESTING MATERIALS

PROPOSED STANDARD SPECIFICATIONS FOR THE ALLOY—COPPER 88 PER CENT, TIN 10 PER CENT, ZINC 2 PER CENT

1. (a) These specifications cover the alloy commercially known as Government bronze, Admiralty gun metal, gun metal, or 88-10-2 mixture, when used in castings.
- (b) It is recommended that this alloy shall not be used where castings are subjected to a temperature exceeding 260° C (500° F).

I. MANUFACTURE

2. The alloy may be made by any approved method.

II. CHEMICAL PROPERTIES AND TESTS

3. The alloy shall conform to the following requirements as to chemical composition:

	Per cent.
Copper.....	87-89
Tin.....	8-11
Zinc.....	1-3

4. (a) The sample for chemical analysis may be taken either by sawing, drilling, or milling the casting or tension test specimen and shall represent the average cross section of the piece.

(b) The saw, drill, cutter, or other tool used shall be thoroughly cleaned. No lubricant shall be used in the operation and the sawdust or metal chips shall be carefully treated with a magnet to remove any particles of iron derived from the tools.

III. PHYSICAL PROPERTIES AND TESTS

5. The alloy shall conform to the following minimum requirements as to tensile properties:

Tensile strength, pounds per square inch.....	33 000
Elongation in 2 inches, per cent.....	14

6. (a) The test bars of the form and dimensions shown in Fig. 1 shall be an integral part of large castings, or cast separately in the case of small castings to represent a lot or melt, and shall be molded in a manner similar to the castings which they represent. If the castings are heat treated, the test bars representing such castings shall be similarly heat treated.

(b) The manufacturer and purchaser shall agree whether test bars can be attached to castings, on the location of the bars on the castings, on the castings to which bars are to be attached, and on the method of casting unattached bars. Unless otherwise agreed upon the minimum lot shall be considered as 500 pounds.

(c) The tension test specimen, turned down from test bar shown in Fig. 1, shall be of the form and dimensions shown in Fig. 2.

NOTE.—Fig. 1 above is understood to be the same as Fig. 1 (a), p. 147 of Vol. XIV, Proceedings, 1914, Part II: Fig. 2 standard 2 by $\frac{1}{2}$ inch threaded specimen.

7. (a) Two tension tests shall be made from each lot or melt.

(b) If any test specimen shows defective machining or develops flaws, it may be discarded, in which case the manufacturer and the purchaser or his representative shall agree upon the selection of another specimen in its stead.

IV. INVESTIGATION OF CLAIMS

8. If the purchaser's tests show that the material does not conform to the requirements specified in section 3, the manufacturer shall have the opportunity to inspect the material and each party shall select a sample for retest. If the results do not agree, each shall select a sample to be final. The costs of retests shall be paid by the loser.



Part II.—MICROSTRUCTURE

I. INTRODUCTION

NOTE.—The work herein described constitutes a part of the study of the properties of the standard zinc bronze (Cu 88, Sn 10, Zn 2), the preparation of which has been described in Part I. The specimens here used are referred to by the same numbers that are there assigned to them.

The various properties of any heterogeneous material depend primarily upon the properties of the units of which it is composed and the method by which these constituents are joined together. Alloys are no exception to this rule. Most of the commercial alloys are fairly complex in their make-up and are composed of units, the different classes of which are often of widely differing properties. The fact that the units out of which the metal or alloy is built are generally of microscopic proportions often leads to their being overlooked and underestimated. Besides the constituents expected to be present, from a knowledge of the chemical composition, various inclusions or contaminations, not added intentionally, often have an important bearing on the properties of the alloy and its behavior in service. A knowledge of the physical structure of any alloy, the characteristic features of each class of structural units, and the method by which the final product is built up out of these is the best foundation for a rational understanding of the properties of the alloy and its probable behavior under varying service conditions.

II. THE EQUILIBRIUM DIAGRAM

Any alloy is most conveniently and properly studied by referring it to its place in the proper series and regarding it as one of a family rather than an isolated individual. By this means any change in properties resulting from changes in composition may be studied systematically rather than at haphazard. The so-called equilibrium diagram represents concisely the structures

existing as a result of varying composition and the structural changes resulting from variations in temperature. For purposes of reference, a portion of the equilibrium diagram of the copper-tin alloys is reproduced. This is one of the most complex of the structural diagrams of the technical alloys, but fortunately the alloy under consideration lies well within the less complex part.

In spite of the great amount of study the alloys of copper and tin have received, there is still no well-defined agreement as to many of the percentage compositions which mark the boundaries of the different structural fields; the limit of the α solution varies from 5 per cent in Giolitti's¹⁵ diagram to 13 per cent in Shepherd's¹⁶. The percentages shown are given by Gulliver¹⁷ and represent conditions of equilibrium, obtained either by excessively slow cooling of the molten alloy or by reheating an alloy which solidified by cooling at an ordinary rate.

Any point of the diagram represents the structure of the alloy at the temperature corresponding to the composition represented by that point. Above the line *ABC* the diagram represents the alloy in the molten state, below *Aa b* the alloy is solid. Between the two, both solid and liquid exist, and in passing through the corresponding temperature range the alloy solidifies or melts according to whether it is being heated or cooled. The diagram shows in a general way the effect of additions of tin upon the melting point of copper.

Alloys of a composition between the points *A* and *a'* consist of but one constituent—the α bronze, which is a solid solution of the two elements, the copper predominating; at *a'* (13 per cent Sn approximately) a second constituent appears and grows in amount as the tin is increased until at 28 per cent (approximately) the entire alloy consists of this second constituent. The properties of alloys lying between *a'* and *d* will depend largely then upon the relative amounts of these two structural units.

The addition of small quantities of zinc does not materially alter the structure of the alloy under consideration. The copper-rich alloys of copper and zinc—i. e., in the α field—are indistinguish-

¹⁵ Giolitti and Tavanti, *Gazetta Chimie*, 38, p. 209, 1908.

¹⁶ Shepherd and Blough, *Jour. Phy. Chemistry*, p. 515, 1906.

¹⁷ Gulliver, *Metallic Alloys*, p. 249.

able microscopically ordinarily from the corresponding ones of the copper-tin series. In speaking of the microstructure of the copper-

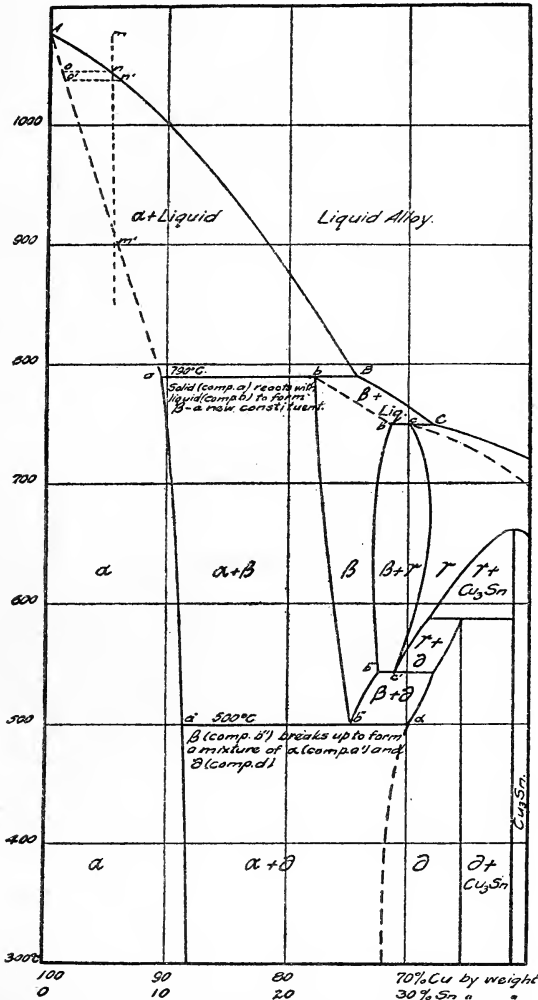


FIG. 10.—Structural equilibrium diagram of copper and tin

rich kalchoids, Hoyt¹⁸ emphasizes the fact that the "microstructure of the ternary alloys corresponds very closely to that of

¹⁸ S. L. Hoyt, Jour. Inst. Metals, 1913, no. 2, vol. X, p. 235.

the two binary systems." The zinc aids materially in the preparation of the alloy by its deoxidizing effect upon any oxides of tin or copper which may be present and causes the metal to be more fluid and thus flow more easily. Any excess of zinc present most probably exists in solution in the α constituent of copper and tin. Fig. 11 shows that portion of the copper-zinc diagram containing the alloys rich in copper. They are simpler than the copper-tin alloys; the α field extends over a much greater part of the series.

If we adopt Guillet's suggestion¹⁹ of the "fictitious value" of an element we may regard the small percentage of zinc added as equivalent in effect to a certain amount of tin in excess of what was actually added. Guillet has determined experimentally that tin has a "coefficient of equivalence" of 2, with respect to zinc as unity. Using the method suggested by Guillet, the 88-10-2 alloy is equivalent in structure to a copper-tin alloy containing 11.1 per cent tin. If this suggestion is followed, as an approximation, for the study of the ternary alloys of copper, tin, and zinc which are low in zinc, it is unnecessary to depend on the ternary diagram of the series.

III. STRUCTURE OF THE CAST ALLOY

The structure of the alloy after solidification and before receiving any treatment, thermal or mechanical, is represented in Fig. 13, *A* and *B*. The structure here shown is that of specimen 19, which was used for the determination of the melting range and the thermal critical points. For the determination of these it was cooled slowly in a Heraeus platinum furnace. The very slow cooling accounts for the coarseness of the structure and also shows the practical impossibility of obtaining a homogeneous alloy directly upon solidification.

The matrix of the alloy shown is the α solution of zinc and tin in copper and shows a fernlike or dendritic pattern. The cores of the individual branches or fingers are the portions very rich in copper and the tin content increases as the outer portion of the "finger" is reached; in the angles between the interlocking branches are the angular inclusions of a eutectoid consisting of two solid solutions of

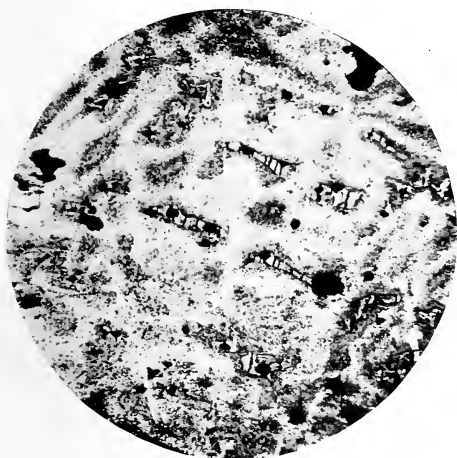
¹⁹ L. Guillet, *Rev. de Métallurgie*, 3, p. 243, 1906, or C. H. Desch, *Metallography*, p. 191.



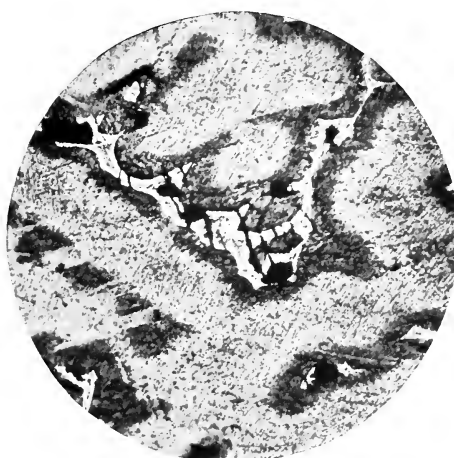
A, Specimen 19; 5X. Remelted and allowed to cool in the furnace. The difference in orientation of the dendritic structure marks out the various crystals



B, Specimen 19; 100X. The dark portions are the cores rich in copper; the light angular spots, the hard brittle eutectoid inclusions



C, Specimen 568; 100X. The shattering of the eutectoid under strain is illustrated



D, Specimen 568; 250X. The cracks (black) in the eutectoid (white) are at right angles to the direction of the strain

FIG. 13.—*Typical microstructure of cast zinc-bronze (88-10-2)*

[A and B were etched with ammonium hydroxide containing hydrogen peroxide; C and D with ammoniacal copper-ammonium chloride]

tin and copper (i. e., disregarding the zinc for the time) of different tin contents. This eutectoid or "bronzite," as it has been termed by Guertler, may be considered as analogous to pearlite in steel.

Reference to Fig. 10 will make clear the process of solidification by which the structure shown is obtained. Assume an alloy of 5

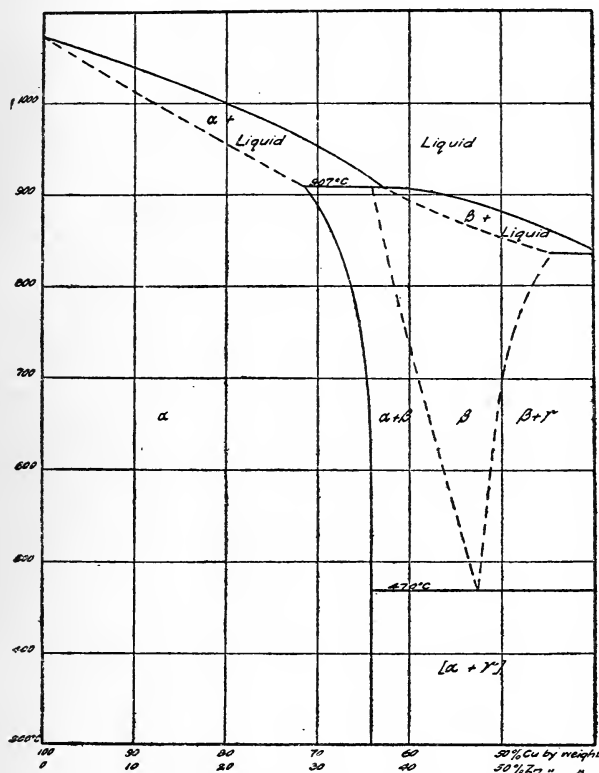


FIG. 11.—Structural equilibrium diagram of copper and zinc

per cent tin in the molten condition, represented by the point *m*. As the liquid alloy cools, solid crystals will first separate out at a temperature of 1050° C (approximately) and be of the composition *o*—approximately 1 per cent tin. The composition of the melt from which these copper-rich crystals separates is represented by *n*. The separation of the copper-rich crystals will increase the

tin content of the liquid portion, its composition now being represented by a point on the curve AC just below n at n' . The composition of the succeeding solid will be correspondingly richer in tin and be represented on the curve at o' . At m' (900°C) the process of solidification is complete and the composition of the solid crystal will vary in tin content from center outward, as represented by the portion of the curve $o-m'$. The process of diffusion which accompanies the precipitation of the crystals tends to wipe out any abrupt changes in composition and only a gradual variation results. The temperature range nm' (1050° to 900°C) is the "freezing range" of the alloy; it has no definite freezing point. Inasmuch as metallic solid solutions do not usually crystallize from a single center outward uniformly but grow in certain directions faster than in others, a treelike form results, the cross section of the branches of which show a varying composition as explained. The central core, being the first to solidify, is the portion richest in copper. Since crystallization begins at a great number of points throughout the cooling liquid metal simultaneously, one such tree-like crystal will result at each center of crystallization, the size and exterior form of each "tree" will depend upon the interference with neighboring ones. The whole mass when solid will consist then of crystals, each one of which may be compared in structure to a solid "double-ended" pine tree. This is shown diagrammatically in Fig. 12.

Below 900°C no further changes occur in the crystals other than diffusion within the crystals, which tends to erase the dendritic pattern and render the structure more homogeneous.

The changes which occur in the 88-10-2 alloy upon cooling are much more complex. The first part of the process of solidification is similar to the alloy just described; in this case the solid separating first from the melt is richer in tin (approximately 3 per cent) than the case already discussed. At 790°C the alloy is nearly solid and consists of dendrites of varying composition (97 to 91 per cent Cu) and a liquid containing 74.5 per cent copper. At this temperature a reaction occurs between this liquid and some of the already solidified portion to form a solid of 77.5 per cent copper content; this is the β solid solution. This β constituent lies in



A, Specimen 524; 5X. Poured as a chill bar at 1285° C.



B, Specimen 524; 100X



C, Specimen 437; 5X. Poured at 1175° C. as a barrel-shaped casting in sand



D, Specimen 437; 100X

FIG. 14.—Microstructure as affected by the rate of cooling

[A and C were etched with ferric chloride; B and D with ammonium hydroxide containing hydrogen peroxide]

the angles between the interlocking fingers next to the tin-rich layers of the dendrites. From 790°C to 500°C , as the alloy, now solid, cools, no appreciable structural change other than diffusion occurs. At 500° , the β solution breaks up into an intimate mixture of the α and δ solutions of copper and tin. The θ solution is still richer in tin than is the β . This break-up at 500° is analogous to the formation of pearlite in steel. The solid solutions α , β , δ , etc., are probably not simple solutions of tin in copper of progressively increasing tin content but their theoretical nature is not of importance here. The 88-10-2 alloy, then, at ordinary

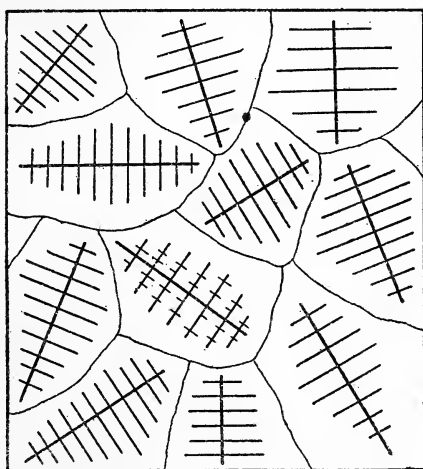


Fig. 12.—Illustration of "pine-tree" or dendritic crystalline structure

temperatures, directly after casting, consists of a mass of solid treelike crystals the branches of which constitute the α solution of tin and copper (plus the zinc) and show a variation in composition from center outward. In the interstices between the "branches" are inclusions of "bronzite," a eutectoid consisting of a mechanical mixture of α and δ solutions of copper and tin which resulted from the break up of a previously existing constituent, the β solution of copper and tin. By increasing the tin content of the alloy the amount of "bronzite" increases at the expense of the α solution until at about 25.0 tin; there is no free α .

Beyond this point free δ solution appears and at approximately 28 per cent Sn the bronzite has disappeared and the alloy is all δ solution.

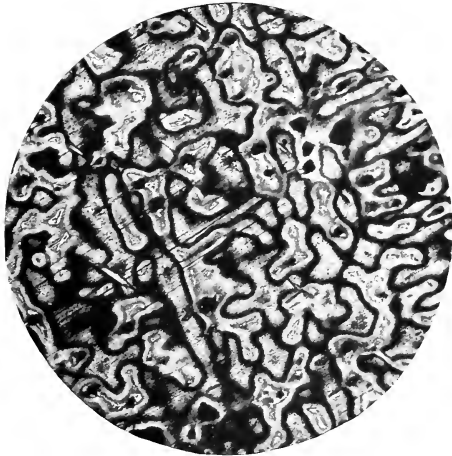
IV. RELATION BETWEEN METHOD OF CASTING AND MICROSTRUCTURE

From theoretical considerations, no essential change in the general microstructure should be expected to accompany different methods of preparation and casting of the alloy. Microscopical examination of some 140 specimens confirms this. The method of casting exerts its influence indirectly by determining the rate of cooling and so also the rate of crystallization. The rate of cooling will be affected by the size of the molding flask, the heat conductivity and capacity of the molding sand, the presence of relatively large quantities of metal in a feeding reservoir, the pouring temperature, the use of chill molds, etc. The term "coarse and fine crystals" has a double meaning with reference to this alloy, and to cast alloys in general possessing a dendritic structure. The size of the individual crystals themselves may vary and so also may the size of the "mesh" of the inner dendritic structure of the crystal. The two are found not to accompany each other, necessarily. The size of the crystals being decided by the number of "crystallization centers," it is to be expected that, ordinarily, a very slow cooling will result in large crystals and a coarse-meshed dendritic structure. Mechanical disturbances, however, may interfere so that crystallization begins at a great many centers and smaller crystals with a fairly coarse interior structure may result with approximately the same rate of cooling. (Compare Fig. 15, *a* and *c*.)

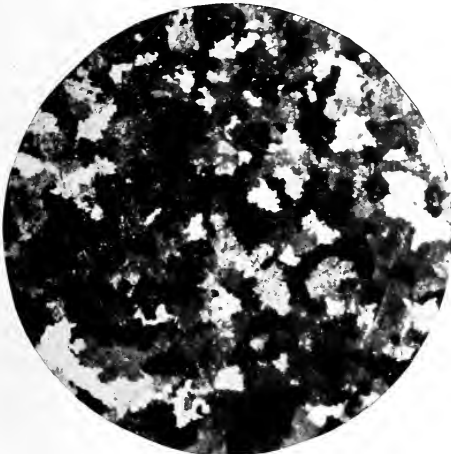
Another important result of the influence of rate of cooling upon the structure is the amount of eutectoid which is dissolved by the α constituent. Theoretically it should be possible with alloys of the percentage of tin here considered to have, at the most, only traces of the eutectoid showing. Practically this never results in the cast alloy. By the use of chill molds, the solidification and the subsequent cooling of the alloy may be so rapid that the eutectoid inversion may be partially obliterated, so that the β constituent is retained, at least in the outer crust thus imparting



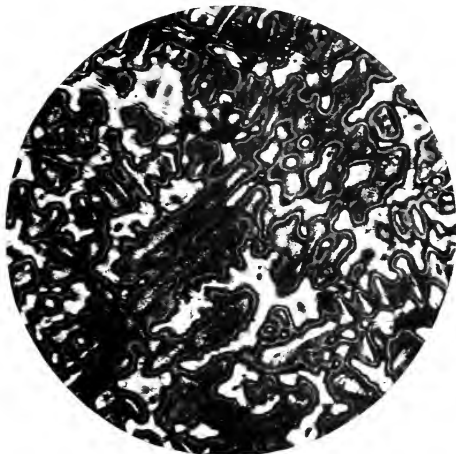
A, Specimen 740; 5X. Poured at 1225° C. as a "cast-to-size" shape in greensand



B, Specimen 740; 100X



C, Specimen 531; 5X. Poured at 1200° C. as a "cast-to-size" shape in greensand



D, Specimen, 531; 100X

FIG. 15.—Microstructure as affected by the rate of cooling

[A and C were etched with ferric chloride; B and D with ammonium hydroxide containing hydrogen peroxide]



different physical properties to the alloy. This condition, however, was not detected with certainty in any of the samples examined.

Figs. 14 and 15 illustrate the general structure of the alloys prepared by different methods and illustrate the above points.

V. APPEARANCE OF SPECIMENS AFTER THE TENSION TEST

The appearance of the specimen after being broken in the tension test is quite indicative of the numerical results obtained in the test. Fig. 16 illustrates this characteristic appearance of "good" and "poor" bars. A knowledge of the microstructure affords an explanation of the cause of this characteristic appearance. Fig. 12 shows that the relative orientation of the interior dendritic structure of neighboring crystals follows no definite plan; this is also confirmed by microscopic observation of the specimens. Those crystals which are most favorably oriented will be stretched beyond the elastic limit first; these most probably are those whose principal axis of orientation coincides with the direction of the applied stress. The roughening or "crinkling" of the surface of the tensile bar shows that different crystals are affected unevenly. In other words, the mechanical properties of the individual crystals are not the same in all directions. When those crystals which are most favorably oriented begin to yield to the stress, thus changing the relative amount other crystals must bear, another set of crystals will reach their elastic limit in that particular direction and so in turn yield to the stress.

Fig. 13, *C* and *D*, show how the different microconstituents behave under tension and what the real nature of each is. The α solution, after its "elastic limit" is exceeded, is plastically deformed by the acting stress. The eutectoid is a hard brittle substance and can only conform to this new condition by breaking transversely across and having the resulting small sections move bodily in the direction of the applied stress. If the eutectoid forms a practically continuous network, its brittleness and other properties will predominate in determining the physical properties of the alloy.

The smooth unwrinkled bars are characteristic of low results in general. In this case the eutectoid is not found in a shattered

condition and the α constituent has not "flowed" under the applied stress. The presence of inclusions of impurities has prevented this and caused the low results. This will be referred to in a later section.

The microscopic examination of the specimen offers evidence of the suggestion made above that the crystals are affected unequally according to their orientation. Crystals were found which showed shattered eutectoid particles and the α matrix in spots has an appearance suggestive of flowing while immediately neighboring crystals apparently were unchanged.

VI. CORRELATION OF MICROSTRUCTURE AND PHYSICAL PROPERTIES

A large number of broken tensile bars were chosen at random for the examination of the microstructure and its correlation with the physical properties. The possible sources of weakness in such bars may be classed under two headings—(1) those due to weakness at the crystal boundaries, badly interlocking crystals, segregated impurities at the exterior of the crystals, etc.; (2) weakness inherent within the crystal structure, which may be due to crystal size and orientation, inclusions of foreign materials, excessive or badly disseminated eutectoid, etc.

TABLE 7

Microscopic Examination

[The specimens given were chosen at random from a collection of nearly 1000 test bars]

Specimen	Condition of bar ^a	Color of fracture	Type of break ^b	Microscopic examination ^c	Physical properties ^d
36	Finely crinkled.....	Rather brown...	Intracrystalline.	Eutectoid moderate in amount; dendrites medium mesh.	42 450 20.5 20.0
109	{Smooth with fine transverse cracks.	{Earthy yellow.....	.....do.....	{Dendrites fine mesh; eutectoid abundant; pits common.	{33 800 6.5 7.0
263	Crinkled.....	Bright yellow.....	.....do.....	{Pits common; trace of oxide film; eutectoid abundant.	{42 000 23.0 16 000 20.0

^a The descriptive terms used are illustrated by Fig. 16.

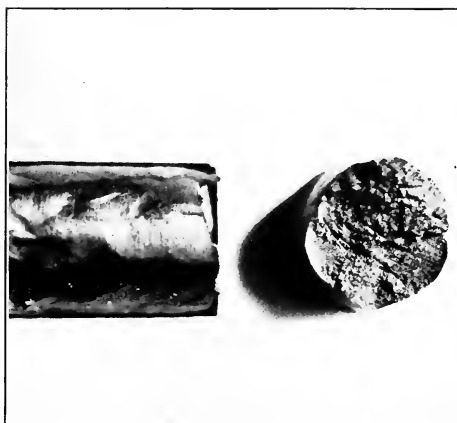
^b Intracrystalline, *through* the crystals; intercrystalline, *between* them.

^c The terms "fine" and "coarse" as applied to the dendritic structure are relative, Fig. 14, *B* and *D*, may be taken as standard. Fig. 14, *D*, also illustrates the usual amount of eutectoid to be expected.

^d Recorded in order: Ultimate strength in pounds per square inch; elastic limit in pounds per square inch; per cent elongation in 2 inches; per cent reduction of area.



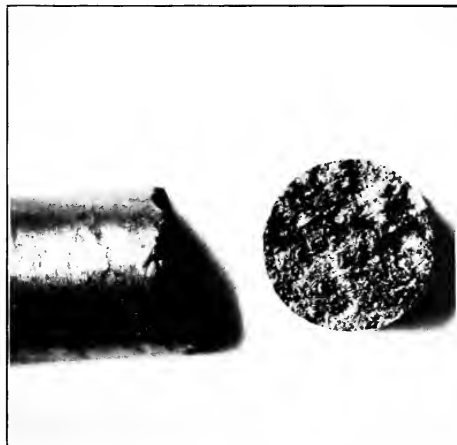
A, Specimen 36; 2X. Ultimate tensile strength, 42,450 pounds per square inch; elongation in 2 inches, 20.5 per cent; reduction of area, 20 per cent



B, Specimen 404; 2X. Ultimate tensile strength, 39,550 pounds per square inch; elongation in 2 inches, 20.5 per cent; reduction of area, 20.5 per cent



C, Specimen 475; 2X. Ultimate tensile strength, 19,800 pounds per square inch; elongation in 2 inches, 3 per cent; reduction of area, 2 per cent



D, Specimen 1023; 2X. Ultimate tensile strength, 26,000 pounds per square inch; elongation in 2 inches, 5.5 per cent; reduction of area, 7.6 per cent

FIG. 16.—Surface appearance of tensile bars after rupture



TABLE 7—Continued

Specimen	Condition of bar	Color of fracture	Type of break	Microscopic examination	Physical properties
285	Finely crinkled.....	Yellow plus orange in depressions.	Intercrystalline.	{No oxide films; eutectoid shattered.	{41 670 21.5 19 000 21.0
301	{Smooth with fine transverse cracks.	Yellowish gray..	{.....do.....	{Coarse mesh for dendrites; eutectoid abundant; oxide films common.	{24 370 7.5 15 000 7.0
312	{Slight roughening of the surface; fracture is through three crystals of nearly same orientation.	Yellow plus a little gray.	{Intracrystalline.	Like No. 314, with less eutectoid.	{32 200 15.0 14 620 11.5
314	{Trace of fine roughening with some transverse cracks.	Yellow plus many bright gray spots.	{.....do.....	{Eutectoid abundant and in relatively large masses; pits abundant; some oxide films found.	{30 900 7.0 17 500 4.0
327	Finely crinkled.....	Dull yellow.....	.....do.....	{Medium mesh; eutectoid, small and scattered; pits few; no oxide.	{40 902 19.0 20 000 16.0
342	Smooth.....	Grayish yellow..	{Crystals too small to decide.	{Poor interlocking of dendrites; eutectoid forms a network; oxide films present.	{23 100 15 550 4.0
372	{Just a trace of crinkling; fine transverse cracks.	.....do.....	{Intercrystalline.	{Dendrites, large mesh; many pits and oxide films.	{25 750 7.5 16 700 7.0
374	{Trace of crinkling of surface.	Orange plus brown.	{Intracrystalline.	{Dendrites, coarse mesh; eutectoid plentiful; pits plentiful; a few oxide films.	{37 120 15.0 16 200 9.0
404	Much roughened	Yellow.....	.....do.....	{Dendrites, large mesh; mesh; trace of oxide films; pits plentiful.	{39 550 20.5 20.5
407	.....	.....	.....	{Dendrites, large mesh; eutectoid in small particles; few pits; no oxide films.	{42 500 23.5 25.7
411	Smooth.....	{Gray plus a little yellow.	{Too finely crystalline to be determined.	{Dendrites are of a very fine mesh and much branched; eutectoid abundant; no oxide films; few pits.	{36 200 5.0 20 000 4.0

TABLE 7—Continued

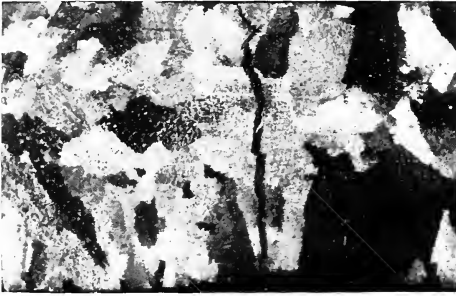
Specimen	Condition of bar	Color of fracture	Type of break	Microscopic examination	Physical properties
416	{ Surface is slightly roughened.	Yellow plus a little gray.	Intracrystalline.	{ Dendrites of large mesh; pits common; some oxide films.	{ 31 200 10.0 16 500 10.5
418	{ Very slightly roughened.	Yellow with distinct tinge of gray.	{ Intracrystalline through a crystal extending one-third the diameter of bar.	{ Dendrites, coarse mesh; eutectoid abundant; pits plentiful; no oxide films.	{ 30 500 12.0 10.0
425	{ Noticeably roughened..	Yellow.....	{ Intracrystalline through a large crystal occupying two-thirds diameter of bar.	{ Dendrites, coarse mesh; eutectoid not abundant; some pits and oxide films, but not abundant.	{ 32 800 13.5 23 800 12.5
431	{ Smooth, with some transverse cracks.	.....	{ Intracrystalline.	{ Many pits; some oxide films.	{ 26 900 7.5 18 500 5.7
439	{ Much crinkled.....	.....	{ do.....	{ Dendrites, medium mesh; eutectoid abundant; no oxide films; pits not common.	{ 44 500 24.0 14.0
445	{ Finely crinkled.....	{ Yellow with a tinge of gray.	{ do.....	{ Traces of oxide films in spots.	{ 41 000 17.0 15.8
447	{ Smooth.....	{ Yellow with orange, also has prominent gray spots.	{ Indeterminable.	{ Dendrites, medium mesh; eutectoid shattered in some crystals; some pits and oxide films found.	{ 33 400 15.0 16 300 16.7
471	{do.....	{ Yellow with a gray tint.	{ Intracrystalline.	{ Dendrites, coarse mesh; pits common with some oxide films.	{ 26 000 8.5 16 000 7.5
472	{ Smooth, with some transverse cracks.	{ Bright orange and brown with some gray spots.	{ Intercrystalline.	{ Eutectoid plentiful and in large particles; pits common; oxide films very bad.	{ 21 000 3.5 15 600 2.5
474	{do.....	{do.....	{ do.....	{ Oxide films very bad..	{ 17 300 2.0 14 800 1.5
475	{ Faint traces of roughening with transverse cracks.	{ Yellow with a tinge of gray.	{ Intracrystalline.	{ Oxide films are abundant.	{ 19 800 3.0 15 000 2.0

TABLE 7—Continued

Specimen	Condition of bar	Color of fracture	Type of break	Microscopic examination	Physical properties
490	Smooth.....	Dirty yellow with brown areas and gray spots.	Intercrystalline.	Oxide films in intercrystalline boundaries, associated with pits; eutectoid in large particles; mesh of dendrites coarse.	14 000 1.0 4 500 .5
494	Very slightly crinkled..	Grayish yellow..		Dendrites, fine mesh; eutectoid, in fine particles; no oxide films; pits not common.	41 400 10.5 3 000 10.5
555	Somewhat crinkled....	Yellow with a tinge of gray.	Intracrystalline.	Dendrites, large mesh; eutectoid not abundant; few pits; trace of oxide films.	36 900 19.5 17.5
568	.....do.....	Dull yellow.....	.....do.....	Dendrites, large mesh; eutectoid shattered in some crystals; pits abundant; some oxide films present.	35 000 21.0 19.0
571	Roughened.....	Yellow.....	.....do.....	Dendrites, large mesh; eutectoid abundant; some oxide films.	30 500 13.0 16.5
573	Roughened considerably.	Dirty yellow.....	.....do.....	Like 568, except eutectoid was not found shattered.	38 500 20.0 16.9
603	Roughened.....		Intracrystalline through a crystal occupying two-thirds the diameter of the bar.	Dendrites, coarse mesh; eutectoid not very abundant; some pits and a trace of oxide films.	37 200 23.5 22.3
613	Smooth, with many transverse cracks.	Orange and dark brown with many gray specks.	Intracrystalline.	Dendrites, coarse mesh; eutectoid plentiful; pits and oxide films rather abundant.	24 100 9.0 7.0
619	Smooth.....		Intercrystalline.	Oxide films and pits abundant.	20 705 3.0 3.8
621	.....do.....		Intracrystalline.	Dendrites, coarse mesh; eutectoid not very plentiful; pits and oxide films fairly abundant.	23 750 5.0 4.6

TABLE 7—Continued

Specimen	Condition of bar	Color of fracture	Type of break	Microscopic examination	Physical properties
640	Fine crinkling.....	{Steel gray with flecks of yellow.	{Intracrystalline.	{Dendrites, coarse mesh; eutectoid very abundant and forms a much-branched network; oxides rare.	{36 300 5.7
819	{Considerably roughened (annealed at 700° C).	.....	.....do.....	{Dendrites gone; eutectoid nearly absorbed; small pits; no films.	{45 500 36.0 30.7
824	{Very slightly roughened (annealed at 600° C).	.....	.....do.....	{Dendrites still show faintly; traces of eutectoid remain; many pits and oxide films.	{34 000 22.0 29.0
831	{Very rough (heated to 700° C and quenched in water).	.....	.....do.....	{Trace of dendrites remain; eutectoid absorbed; some pits show.	{40 000 37.0 32.4
836	{Very rough (annealed at 800° C).	.....	.....do.....	{Dendritic pattern entirely gone; eutectoid absorbed; a few very tiny pits.	{47 000 40.0 34.0
838	{Very rough (annealed at 700° C).	.....	.....do.....	{Like No. 836; also a faint trace of oxide film was found.	{48 500 42.0 19.0
1006	Finely crinkled.....	{Yellow with a little gray.	.....do.....	{Eutectoid not very abundant; dendrites coarse; some oxide films are present.	{35 600 19.5 16.9
1009	Roughened at one end.	Grayish yellow ..	.....do.....	{Dendrites, fine mesh; eutectoid plentiful; pits and fine oxide films.	{32 100 7.0 8.4
1014	Somewhat roughened..	{Yellow with trace of brown in spots.	.....do.....	{Eutectoid not very abundant and in fine particles; some pits and a trace of oxide films.	{35 000 10.5 19.0
1023	Smooth.....	{Orange brown with grayish yellow in spots.	.....do.....	{Dendrites, very fine mesh; eutectoid abundant; some oxide films.	{26 000 5.5 7.6



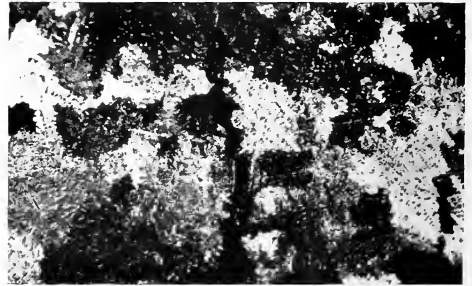
A, Specimen 285; 3X



B, Specimen 571; 3X. The large crystal extending nearly across the bar most probably determined the position of the break



C, Specimen 312; 3X. The three crystals of nearly the same orientation act similarly to a single crystal



D, Specimen 301

FIG. 17.—*Types of fracture: Inter-crystalline and intra-crystalline*

A, B, and C, intra-crystalline; D, inter-crystalline

1. TYPE OF FRACTURE

An interesting and important point is the determination whether, during tension, the break finally occurs between or through the crystals. These two types of break may be termed intercrystalline and intracrystalline, respectively. To determine this point the two parts of a good many broken tensile specimens were soldered accurately together and a longitudinal section cut through the soldered portion of each bar. The cut face was polished and etched to reveal the macroscopic crystalline structure. The results are summarized in the preceding table. Fig. 17 illustrates the appearance of several such bars and show clearly that the prevailing type of break is the intracrystalline one rather than a simple pulling apart of the crystals, as might be supposed. Rosenhain ²⁰ has already called attention to the fact that this type of break is characteristic of metals broken at ordinary temperatures. Of 44 bars examined the following results were obtained.

	Number	Per cent
With intracrystalline break.....	35	79.6
With intercrystalline break.....	6	13.6
Indeterminable.....	3	6.8
Total.....	44	100.0

This is true of many of the specimens which remained smooth after breaking and which gave evidence of very low ductility, thus showing that even in such cases the region of the crystal boundaries is stronger than the interior of the crystals themselves. The specimens giving an intercrystalline break were those showing the worst mechanical features of all those examined.

2. COARSENESS OF THE DENDRITES

The results obtained indicate that the size of the mesh of the dendritic structure is relatively a minor factor in determining the physical properties of the alloy. High tensile results were noted with specimens in which the interior crystalline structure was

²⁰ Jour. Inst. of Metals, 1913, 2, x. p. 119. "The Intercrystalline Cohesion of Metals."

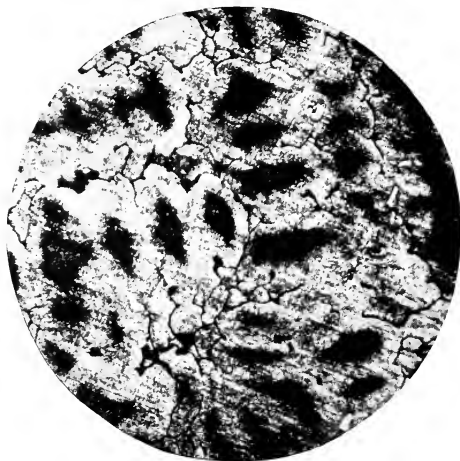
relatively coarse, e. g., specimen 407. With very pure material, the coarseness of the dendritic structure undoubtedly will be an important factor in determining the physical properties of the alloy, but with commercial material other factors overshadow this one as shown by the results obtained in this series.

3. EUTECTOID

As is to be expected, any decided increase in the amount of a brittle constituent like the eutectoid found in this alloy will entail decided changes in the physical properties. In dealing with any series, however, in which the composition is fixed within rather narrow limits, as is the case here, the distribution and arrangement of this constituent rather than accidental variations in the amount are more important in determining the properties of the alloy. Two specimens in the series examined, Nos. 411 and 640, showed no decided bad features so far as inclusions, etc., are concerned. The dendrites, however, instead of forming the usual interlocking type with the eutectoid forming isolated masses in the angles of the branches, are of a more open form and the eutectoid forms a nearly continuous network enveloping the branches. Both of these specimens broke with a decided gray fracture and though the ultimate strength was near the average the specimen showed the characteristics of brittleness to be expected. This type of structure, however, was the exception rather than the rule in the observed series. Fig. 18, *D*, illustrates this condition.

4. SIZE AND ORIENTATION OF CRYSTALS

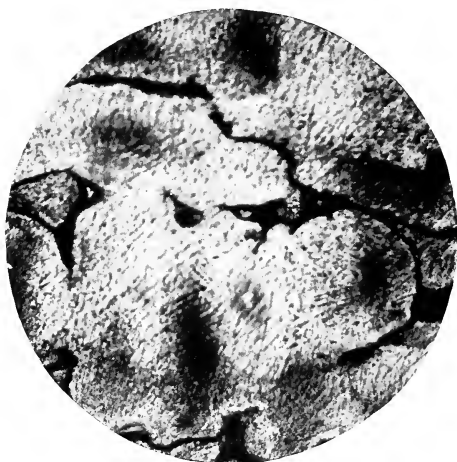
In otherwise good and clean metal, the size and orientation of neighboring crystals will determine largely the properties of the materials. Specimens 425 and 603, while showing a fair structure otherwise, broke at a point where one crystal extended nearly two-thirds the diameter of the bar. The properties of this crystal then determined almost entirely the behavior of the whole bar; Fig. 16, *B*, illustrates this condition. Several adjacent crystals having nearly the same orientation will act in a manner very similar to a single large one; such a specimen is illustrated in Fig. 16, *C*. Such cases are apparently unavoidable and must be expected to occur in castings, as ordinarily prepared.



A, Specimen 475; 100X. The dark network is the film of oxide



B, Specimen 475; 250X



C, Specimen 613; 250X



D, Specimen 411; 100X

FIG. 18.—*Microstructure of badly contaminated metal*

A, B, and C show the appearance of the oxide films; D illustrates the open dendritic mesh (dark) with a fairly continuous eutectoid network (light). [All were etched with ammonium hydroxide containing hydrogen peroxide]

5. OXIDE FILMS AND PITS

The one predominating cause of low results, as illustrated by the series examined, is the presence of oxide inclusions. In speaking of this point Law ²¹ says:

So important is the deoxidation of metals and alloys that it would probably be no exaggeration to say that when the history of the alloy industry comes to be written, the record of progress during the past 20 years will be summed up in the words "the use of deoxidizers."

In order to check out the possible occurrence of iron as an impurity in some of the bars which gave especially low results a qualitative test was made. A 5-gram sample of specimen 474, one of the poorest and most brittle bars examined, was used. No detectable color was obtained with the potassium sulphocyanide test.

The form in which an impurity occurs, rather than its actual amount, largely determines the deleterious effect produced. The work of Heyn and Bauer ²² has shown that in the copper-tin alloys stannic oxide inclusions occur in the form of an intersecting network. Similar networks were found in many of the samples examined. Fig. 18, A, B, and C, shows their appearance. In many of these networks dove-gray inclusions were found. Most of them, however, were filled with a pulverulent form of oxide. The oxide is really in the form of films of which the network observed is the cross-sectional view. These films are found within the dendritic structure of the crystals, in the tin-rich portion, or in that portion solidifying toward the close of the solidification period. Consequently, they are found in conjunction with the eutectoid, which is often noticed to form a continuation of the film. Thus, the bad effects of each are enhanced. In addition to the oxide films, most of the specimens show porosity to a greater or less extent. In many cases these pores are filled with the same pulverulent form of oxide found in the films. These pits are usually associated with the films in case the latter are present.

An inspection of the results given in Table 7 shows that of those specimens having an ultimate tensile strength of 30 000 or less,

²¹ E. F. Law, *Jour. Inst. of Metals*, 1912, No. 2, p. 222.

²² *Zeit. für Anorg. Chemie*, 1905, 45, p. 52; E. Heyn and O. Bauer, "Kupper, Zinn, und Sauerstoff."

13 in number, all show numerous oxide films and pits. Of the 12 specimens having an ultimate strength of from 30 000 to 35 000, 10 show evidence of these films of oxide. The presence of oxides of tin and zinc in the form of pits and films may be considered, then, as a predominating factor in the cause of weakness in cast bronze. The color of the freshly broken fracture suggests that often cuprous oxide may be present. Of the two forms, the films are much more serious in the results than are the pits and blow-holes. Samples in which the oxide occurs almost exclusively in relatively large masses rather than thin, wide-spreading films, while possessing a lower ultimate strength and elastic limit than sound metal, show evidence of higher ductility, and on the whole appear as a much better grade of material than those in which the films predominate. Specimen 374 is an example of this.

The question of the solubility of oxides in metals is of prime importance in the consideration of means to be taken for their elimination. Law, in the reference already cited, states that with the exception of cuprous oxide, the solubility of which in copper is well known, other oxides do not dissolve to any appreciable extent in the molten alloy. Heyn and Bauer found in their work on stannic oxide that it is not soluble in the alloy. The forms in which the oxides were always found to occur in the samples examined, either in pits or films, is evidence that they are held in mechanical suspension rather than in true solution.

The work of Heyn and Bauer, already referred to, has shown that a covering of charcoal is not a sufficient protection against oxidation for copper-tin alloys. The results obtained here suggest that zinc as a deoxidizer is not to be depended upon without more elaborate precautions than can usually be taken in the ordinary course of brass foundry work.

6. CONCLUSION

The general conclusion from the study of the microstructure is that the presence of oxides is a much more potent source of mechanical weakness of the alloy in its cast condition than any of the other causes enumerated. From the standpoint of microstructure, the variations in methods of casting, pouring tempera-





A, Specimen 418; 5X. The right edge shows a trace of the peripheral layer of fine recrystallized metal due to the surface distortion of the tensile bar while being machined; heated for 30 minutes at 700°C. and cooled in the furnace. The macroscopic crystalline appearance of the greater part of the bar has been unchanged



B, Specimen 418; 100X. From the central portion of A. The eutectoid has been nearly absorbed by the matrix; the dendritic pattern has been partially erased



C, Specimen 418; 100X. Part of the recrystallized peripheral layer of A



D, Specimen 451; 100X. From the outer portion of the tensile bar where the structure was distorted by machining; heated to 866°C., dropped to 700°, held 30 minutes and then cooled in furnace

FIG. 19.—Microstructure as affected by heat treatment

[A, C, and D were etched with ferric chloride, B with ammonium hydroxide containing hydrogen peroxide]

ture, etc., are to be regarded primarily as means for the production of sound oxide-free material and to confer no mysterious properties upon the alloy. The frequent occurrence of oxides in this series, prepared under careful supervision and using precautions for avoiding such contaminations, suggests the abundance of such inclusions in similar alloys as prepared commercially. The failure of such cast alloys for many purposes is most probably to be ascribed to the presence of oxide films rather than to any other cause.

VII. MICROSTRUCTURE AS RELATED TO HEAT TREATMENT

As recorded in the microstructure, the effect of annealing the alloy will be revealed by the disappearance of the interior dendritic structure of the crystals, the solution of the eutectoid in the α matrix, and the recrystallization of the alloy into the well-known polyhedral forms so characteristic of annealed brass and bronze high in copper.²³ Heating, followed by quenching, will retain the alloy in some intermediate stage depending on the temperature, time of heating, etc. The quenching of bronzes higher in tin may involve the retention of the β solution which exists above 500° C (Fig. 10). This, however, may be disregarded here. Fig. 19, A, B, C, and D, shows the effect of heat treatment upon the structure.

The changes observed in the properties of heat-treated specimens (Table 7, Nos. 819, 824, 831, 836, 838) are most probably to be attributed to the disappearance of the nonhomogeneity of the alloy by the intracrystalline changes, i. e., by the erasure of the dendritic structural pattern, and the absorption of the eutectoid by the α matrix. This hard and brittle constituent, existing in a multitude of tiny inclusions throughout the alloy, almost entirely disappears. It is to be inferred from the examination of fractured test bars (Sec. VI, 1) that it is the intracrystalline changes upon annealing rather than those at the boundaries that most affect the properties of the metal as a whole.

²³ This is true only in case the metal has been "cold worked" and hence distorted as is true here for the surface layer of the test bars. Unworked castings will show no "recrystallization" upon annealing.

In speaking of the effect of heat treating this alloy, Primrose²⁴ mentions the growth of the original crystals and the coarsening of the dendritic pattern upon annealing. In none of the heat treated specimens examined was any evidence of an increase of crystal size found. As the dendritic structure disappears upon heating, the copper-rich cores spread by diffusion and the rather sharp outlines of this pattern disappear. Thus, the whole structure appears coarser than before but it should not be considered as analogous or similar in properties to a dendritic structure which, directly after casting, is as coarse as this heat-treated one now appears to be.

The effect of heat treatment upon badly oxidized metal is important. The results obtained for specimen 824 illustrate that the bad effects upon the tensile properties can be partially eliminated; this sample, though badly pitted and showing oxide films, gave a fair ultimate tensile strength and high ductility. The heat treatment of this alloy was carried out with a different aim in view. However, the results suggest that a series of heat treatments of badly oxidized specimens with the special purpose of determining whether it is possible to convert the injurious films of oxide into other less objectionable forms would be valuable.

VIII. ETCHING OF SPECIMENS

The structure of the alloy is revealed by appropriate etching. The oxide pits and films are seen before etching, though they are most clearly revealed after the surface film of metal due to the polishing is dissolved off by the etching fluid. For showing the macroscopic crystalline appearance directly after casting, a freshly prepared saturated alcoholic solution of ferric chloride is very suitable. If the etched specimen, after being washed in alcohol and dried, is coated with a thin layer of clear shellac, the contrast between the crystals is greatly increased. This is valuable for photographic purposes. To reveal the dendritic structure of the crystals, a 1-1 (approximate) solution of ammonium hydroxide, to which one or two drops of hydrogen peroxide are added while the specimen is immersed, may be used. The copper-rich

²⁴ Jour. Inst. Metals, 1913, No. 1, Vol. 11, p. 158.

portion, or cores, are attacked most strongly and dissolved so that the tin-rich portions appear in relief. The eutectoid is but little affected and shows in good contrast against the etched background. The same structure is shown by the use of an alkaline solution of copper ammonium chloride. In this case the surface is not etched so deeply. An acid aqueous solution of ferric chloride (5 per cent solution acidified with 1 per cent of hydrochloric acid) is often used. This darkens the α matrix so that the eutectoid stands out in bold contrast. It has the disadvantage of not clearly showing the dendritic structure of the matrix.

IX. SUMMARY

(a) The addition of the small percentage of zinc does not affect the theoretical microstructure of the alloy.

(b) The method of casting, pouring temperature, etc., affect the structure only indirectly by influencing the rate of cooling, amount and distribution of "inclosures," etc.


(c) The microstructure offers an explanation for the characteristic appearance of the tensile bars after testing.

(d) Of the various microstructural features affecting the physical properties, oxide films must be considered to exert the greatest influence, by far.

(e) The changes of microstructure accompanying annealing are explained and illustrated.

The very efficient help given by Arthur C. McCabe in the preparation of the many metallographic sections necessary for examination in this study is much appreciated and is here acknowledged.

WASHINGTON, March 25, 1915.









(Continued from p. 2 of cover.)

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